UNCLASSIFIED

AD NUMBER	
AD109764	
CLASSIFICATION CHANGES	
TO:	**UNCLASSIFIED**
FROM:	**CONFIDENTIAL**
LIMITATION CHANGES	
TO:	**Approved for public release; distribution is unlimited. Document partially illegible.**
FROM:	**Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1951. Other requests shall be referred to Office of Naval Research, Washington, DC 20350. Document partially illegible.**
AUTHORITY	
31 jan 1963, DoDD 5200.10; onr ltr 26 oct 1977	

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

UNCLASSIFIED

AD ________

Reproduced
by the

ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA

DOWNGRADED AT 3 YEAR INTERVALS:
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10

UNCLASSIFIED

~~CONFIDENTIAL~~

AD 109764

Armed Services Technical Information Agency

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

This document is the property of the United States Government. It is furnished for the duration of the contract and shall be returned when no longer required, or upon recall by ASTIA to the following address: Armed Services Technical Information Agency, Document Service Center, Knott Building, Dayton 2, Ohio.

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

~~CONFIDENTIAL~~

109764

DETAILED FINAL REPORT OF RESEARCH ON HIGH-SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME IX

AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED, EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS AS MEASURED IN THE UWAL WIND TUNNEL

OFFICE OF NAVAL RESEARCH, AMPHIBIOUS BRANCH
PROJECT NR 250-001 CONTRACT N9onr-84901

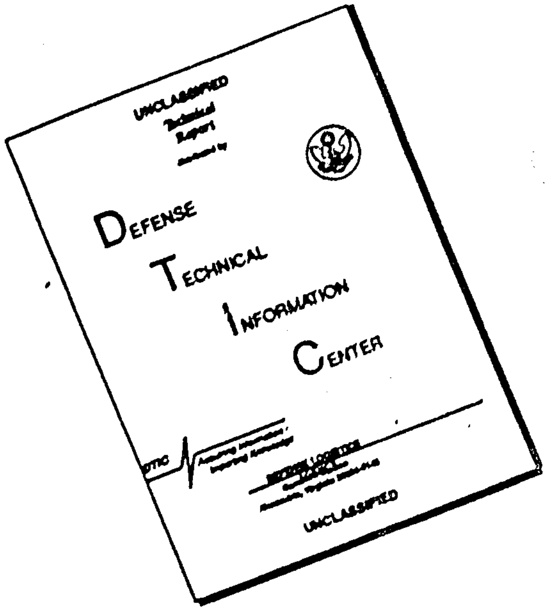
Report 1975 Serial 4

22 January 1951

OCT 1956
54AA 3740

NOTICE: THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 and 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

MAC 273 (REV. 2-24-50)

CONFIDENTIAL

REPORT 1975

DATE 22 January 1951

REVISED

McDONNELL Aircraft Corporation

ST. LOUIS 3, MISSOURI

DETAILED FINAL REPORT OF RESEARCH ON

HIGH SPEED ROTARY-FIXED WING AIRCRAFT

VOLUME IX

AERODYNAMIC CHARACTERISTICS OF A TWO-BLADED,

EIGHT-FOOT ROTOR MODEL AT HIGH TIP-SPEED RATIOS

AS MEASURED IN THE NAVAL WIND TUNNEL

SUBMITTED UNDER C ntract N9o 01 to the Office of Naval Research, Amphibious Branch, Project NR 250-001

PREPARED BY R. E. Head K. H. Hohenemser

R. E. Head K. H. Hohenemser

APPROVED BY

APPROVED BY C. H. Hurkamp

C. H. Hurkamp

CONFIDENTIAL

TABLE OF CONTENTS

1.0 SUMMARY

The results of two model test programs investigating the aerodynamic characteristics of a two bladed, see-saw rotor in the range of very high tip-speed ratios are presented in this report. This experimental work was done under contract for the Office of Naval Research and is the first portion of a broad program for investigating the characteristics of a rotor-fixed wing type of aircraft.

This report presents data for the rotor operating in the range of advance ratios from $\mu = 0.5$ to $\mu = 3.0$.

2.0 INTRODUCTION

Early in 1949 a contract was entered into by the Office of Naval Research and McDonnell Aircraft Corporation for research into the problem of the rotor-fixed wing aircraft configuration. It was held that in order to accomplish high level flight speed of the order of 300 to 400 miles per hour, it would be necessary to have the rotor operate at tip-speed ratios very much higher than are conventionally used in helicopters and autogyros.

Consequently, the test program reported herewith was undertaken. The rotor model used was a two-bladed, see-saw type of rotor which was built from a salvaged rotor of the XH-20, "Little Henry", helicopter. The diameter of rotor was reduced and a special hub mounting was devised for mounting the rotor in the twelve foot UWAL wind tunnel at the University of Washington, Seattle, Washington. The prototype rotor was postulated as a pressure-jet type of rotor having burners at the blade tips. To simulate the drag of such tip-burners, small spheres of various sizes were attached to the tips of the model blades.

The first series of tests with this rotor during July, 1949, clearly demonstrated the possibility of using a rotor at very high advance ratios where the efficiency of the rotor is considerably improved over the low advance ratio operation. However, it also became clear that the rotor was quite sensitive to small changes in rotor attitude.

After this first series of tests, the model was modified to eliminate most of the drag of the blade hub fittings which proved objectionable in the previous tests. This entailed reducing the diameter of the rotor slightly and construting a lens-shaped fairing for the rotor hub. Further, a device

was designed for automatic control of the rotor attitude which was to govern the speed of the rotor.

The second series of tests was then conducted in the UWAL wind tunnel during October, [illegible]. These tests covered the high range of tip-speed ratios ($\mu = 0.5$ to $\mu = 2.5$) and a large range of blade pitch angles ($\theta = +3.0^\circ$ to -4.0°) for autorotation and for both accelerating and decelerating torques applied to the rotor. The aerodynamic characteristics of the rotor as determined by these tests were in reasonable agreement with the characteristics as determined theoretically in Reference 1.

The governor, while capable of stabilizing the rotor speed for small attitude changes, would require major modifications in order to correct larger attitude changes.

3.0 DISCUSSION

3.1 Purpose of The Tests - The purpose of the first series of tests was to investigate the feasibility of operating a rotor at unconventionally high advance ratios and to provide preliminary data required for a later and more complete test program.

The second series had the following purposes:

a. Check the operation of the automatic rotor attitude control.

b. Determine the aerodynamic characteristics of the modified rotor model without hub fairing.

c. Determine the influence of the lens-shaped hub fairing.

3.2 Test Equipment -

3.2.1 The Model -

3.2.1.1 First Series of Tests - The rotor model used in the first series of tests was a rotor which had been salvaged from the XH-20 "Little Henry" helicopter and modified for use in the wind tunnel (See Figures 1 and 2). The outer portions of the blades were removed to reduce the diameter to eight feet. Provision was made for mounting small spheres on the tips of the blades to simulate the effect of tip-jet units (See Figure 3). The hub was modified to allow the installation of a small electric motor for providing accelerating and decelerating torques to the rotors; an electric tachometer generator was also incorporated. Figure 4 shows the hub mechanism and the rotor control panel is shown in Figure 5.

3.2.1.2 Second Series of Tests - For the second series of tests the model was modified somewhat. The hub fittings for the blades were greatly reduced in size to eliminate most of their drag (See Figure 6 and 7). This necessitated reducing the rotor diameter from eight feet for the original model to 7.58 feet. A lens-shaped fairing was designed to cover the blade hub fittings (See Figures 6 and 7).

A rotor attitude control governor was incorporated for stabilizing the rotor in the high advance ratio range. This governor was a modified Curtiss electric propeller governor which was driven by a flexible shaft from the rotor and stabilized the rotor speed by energizing an electric linear actuator which varied the rotor attitude in the wind tunnel. The model with the governor and the necessary control equipment is shown in Figure 8.

3.2.1.3 Model Data

	First Series	Second Series
Rotor diameter, feet	8.00	7.58
Number of blades	2	2
Blade chord, inches	6.2	6.2
Blade planform	Rectangular (extends from 1.4 ft. radius to 4.0 ft. radius.)	Rectangular (extends from 0.54 ft. radius to 3.79 ft. radius.)
Solidity Ratio	.082	.087
Blade Twist	None	None
Airfoil section	NACA 0013	NACA 0013
Rotor type	See-saw blades	See-saw blades

3.2.2 Instrumentation

3.2.2.1 Standard Wind Tunnel Instrumentation - The standard wind instrumentation was used to measure three components in addition to the tunnel speed:

a. lift

b. drag

c. yawing moment (a measure of the torque of the rotor)

Figure 9 shows the instrumentation on the photo-panel for the tunnel balance system. The balance is capable of measuring six components but only the three listed above were of interest in these tests. The instruments shown in Figure 9 are as follows:

1. Rotor RPM indicator, showing double rotor RPM
2. Angle of attack of rotor,
3. Clock
4. Angle of yaw, was zero for all tests
5. Drag force, switch on left side indicates sign of drag force. Switch on right side gives the total range of instrument scale in pounds
6. Lift force, switches to left and right same as before
7. Side force, positive if to the right, seen in upwind direction, switches to left and right same as before
8. Pitching moment positive if tail heavy, around the moment center, which is 5.8" below the hub center. Switches to left and right same as before, except that switch on right side gives the total range of instrument scale in inch pounds.
9. Rolling moment, switches to left and right same as before

10. Yawing moment, positive if clockwise seen from above, which is an accelerating air moment for the rotor, switches to left and right same as before.

11. Dynamic pressure deviation from q_c value as indicated in the upper right corner of the panel.

12. Air temperature indicator

13. Barometric pressure indicator

3.2.2.2 Special Instrumentation for the Rotor Model - Extra instruments were required for the rotor model. These were:

a. rotor speed indicator (indicated 2 x RPM and was connected in parallel with the tachometer on the photo panel).

b. rotor driving motor ammeter

These instruments were located on the rotor control panel shown in Figure 5.

In addition, a special protractor was employed to measure the rotor tip-path plane angle of inclination. This angle was observed visually using the device shown in Figure 10.

3.3 Operating Limitations -

3.3.1 First Series of Tests -

3.3.1.1 See-saw Angle Limitation - (approximately ± 12°) Under some test conditions this limitation was difficult to observe and the blades hit the stops several times, leading to heavy vibrations and to destruction of safety flexures in the tunnel balance system.

3.3.1.2 Rotor Angle of Attack Limitation - The upper limit of rotor angle of attack was given by interference with the fairing around the center

portion of the model, approximately +15°. The lower limit of α was given by operational limitations and varied with rotor pitch angle from +2° to +6°.

3.3.1.3 Torque Limitation - The accelerating or decelerating torque limit was given by the electric motor and by the gears between rotor shaft and electric motor, approximately ± 20 inch pounds. Torques of +12 and -15 inch pounds, corresponding to ±10 amps. in the armature of the electric motor could be maintained continuously throughout the tests.

3.3.1.4 RPM Limitations - A severe resonance of the model supports and balance system was encountered at about 600 RPM. Replacing the metal ring around the lower shaft bearing by a soft rubber ring lowered the resonance frequency somewhat, but running through the resonance range caused severe vibrations and the breaking of safety flexures in the balance system. The original metal ring was, therefore, reinstalled and the operating rotor RPM was limited to 500 RPM.

3.3.1.5 Tip Speed Limitation - The highest RPM for safe operation was 500 RPM which corresponded to a maximum tip speed of ΩR = 210 ft./sec.

3.3.1.6 Advance Ratio Limitation - The highest advance ratio which was measured was μ = 3.0. With increasing advance ratios the rotor became increasingly unstable and it was not possible to obtain steady conditions for high advance ratios.

3.3.1.7 Blade Pitch Angle Limitation - The instability mentioned before increased with blade pitch angle. The highest blade pitch angle for which

fairly steady conditions could be reached up to μ = 2.0 was θ = +8°. The limitation in negative blade pitch angle was θ = -8° and was given by the maximum flapping angle of ±12° of the blades which increases with blade pitch angle and with advance ratio, μ. The configuration with θ = -8° could, for this reason, only be measured up to an advance ratio of μ = 1.5. Within the measured blade pitch angle range from + 8° to -8° no difficulties were encountered in starting the rotor.

3.3.2 Second Series of Tests - The limitations were about the same as those described above except for the RPM limitation. The severe resonance which was observed for the first model at 600 RPM was reduced to 450 RPM because of the greater elasticity of the blade root section. Most of the tests were conducted at below resonance rotor speeds. Some of the tests at above resonance rotor speeds and some tests which were inadvertently run in the resonance range resulted in breaking the flexures in the tunnel balance system.

3.4 Test Procedure

3.4.1 First Series of Tests - After a few preliminary runs to check out the apparatus, the following test procedure was adopted:

a. Set the blade pitch angle.

b. Install the tip-drag spheres if required for the particular test.

c. Establish a nominal rotor speed of 375 rpm.

d. Establish the proper tunnel speed to obtain the desired advance ratio.

e. Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.

f. Introduce an accelerating or decelerating torque as required and repeat (c), (d) and (e) above.

3.4.2 Second Series of Tests

3.4.2.1 Tests Without Automatic Rotor Attitude Control - The procedure for these tests was as follows:

a. Set the blade pitch angle.

b. Install the tip-drag spheres if required for the particular test.

c. Establish a nominal rotor speed and tunnel speed in accordance with the following table:

μ	.5	.75	1.0	1.25	1.5	2.0	2.5
ΩR mph	149	128	112	99.5	89.5	74.5	64
V, mph	74.5	96	112	124	134	149	160
q, lb/ft^2	14	23.5	32	39.5	46	56.5	65
RPM	550	475	415	470	330	275	235

The RPM was different for each advance ratio so as to obtain a constant tip speed at the advancing blade rather than a constant RPM as in the first test series. The constant tip speed tests give a more realistic picture of the rotor characteristics since the actual aircraft probably will operate under the same conditions. The tip speed at the advancing blade was chosen as 225 mph.

d. Take photo-panel picture and simultaneously observe and record the tip-path plane angle of attack.

e. Introduce an accelerating or decelerating torque as required and repeat (c) and (d) above.

3.4.2.2 Tests With Automatic Rotor Attitude Control - The procedure for these governor tests was as follows:

a. Set zero blade pitch angle

b. Establish rotor and tunnel speeds in accordance with (e) of Section 3.4.2.1.

c. Apply a sudden one degree rotor attitude disturbance.

d. Observe the amplitude of the RPM oscillations and the time required for the disturbance to subside.

3.5 Test Results

3.5.1 First Series of Tests - The first series of tests was intended mainly as a preliminary investigation of the feasibility of operating a rotor at unconventionally high advance ratios. It was demonstrated that advance ratios of the order of 2.5 to 3.0 were possible so the second test series described below was planned to fully investigate the high advance ratio range.

No quantitative data are given for the first test series because they are of doubtful value as a result of the poorly designed hub which increased the drag of the rotor considerably and contributed essentially no lift.

3.5.2 Second Series of Tests -

3.5.2.1 Corrections to Photo-Panel Data -

a. α Correction:

The indicated values of α were within 0.1° of being identical with the actual values and no correction was necessary. The wind

tunnel wall correction of α was in the order of 0.1° and, therefore, negligible.

b. Lift Correction -

The lift was corrected for the hub lift which was determined by tests without blades. The hub lift is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$L' = L - L_H$$

where L_H (lb.) =	0.5	0.9	1.2	1.3	1.5	1.9	2.2
for q (lb./ft^2) =	14	23.5	32	39.5	46	56.5	65

The wind tunnel wall correction for the lift is negligible because of the small lift coefficient (maximum $C_L = 0.02$).

c. Drag Correction -

The drag was corrected for the hub drag as determined by tests without blades. The hub drag is approximately independent of the angle of attack of the rotor and of the rotor RPM and only dependent on the tunnel speed. The following values were used:

$$D' = D - D_H$$

where D_H (lb.) =	1.7	2.8	3.8	4.7	5.4	6.7	7.7
for q (lb./ft.^{2})	14	23.5	32	39.5	46	56.5	65

The wind tunnel wall correction for the drag is negligible as for α and for the lift.

d. Torque Correction -

The yawing moment, M_y, is approximately equal to the rotor torque, since the shaft axis was inclined only a few degrees with respect to the vertical axis. The torque was corrected for the hub torque. The following values were used:

$$M_Y' = M_Y - M_{Y_H}$$

where M_{Y_H}	(in.-lb.) =	-.8	-.9	-.9	-.9	-.9	-.9	-.9
for q	(lb./ft.^{2}) =	14	23.5	32	39.5	46	56.5	65

e. Lift to Drag Ratio Correction -

The lift to drag ratio of the rotor was corrected for rotor torque by using instead of the drag, D', the value:

$$D'' = D' - \Delta D$$

where $\Delta D = \dfrac{M_Y'}{\mu R}$ (R = rotor radius)

L'/D'' is the equivalent lift to drag ratio and is usually looked upon as an appropriate efficiency figure for a rotor.

3.5.2.2 Transfer of Data to Coefficient Form - The force and moment measurements were converted into coefficient form by the following equations:

$$\Omega R\text{, mph} = 0.135\ \text{RPM}$$

$$\mu = \frac{V_{mph}}{(\Omega R)_{mph}}$$

$$C_L = \frac{L'}{\pi R^2 q}$$

$$C_T = \frac{\mu^2 C_L}{2}$$

$$C_Q = -\frac{M_Y' \mu^2}{\pi R^3 q}$$

$$C_D = \frac{C_L}{(L'/D'')}$$

3.5.5 Sample Plots of Data

3.5.5.1 Thrust Coefficient - Figure 11 shows the thrust coefficient, C_T, against α for zero tip drag and for a blade pitch angle, $\theta = -1.5°$. The slope of the $C_T - \alpha$ curve becomes very steep at higher advance ratios, μ . The blade loadings, (C_T/σ), reach extraordinarily high values at high advance ratios. (C_T/σ) values up to 0.35 were measured. The autorotation curve indicates clearly the instability at higher advance ratios. Above $\mu = 1.25$ this curve is nearly vertical and small changes in α have a very large effect on the equilibrium advance ratio, μ ; that is, on the equilibrium RPM. Below $\alpha = 4°$ no autorotation is possible.

3.5.5.2 Torque Coefficient - Figure 12 shows the torque coefficient, C_Q , plotted against α for zero tip drag and for a blade pitch of $\theta = -1.5°$. Positive C_Q corresponds to power input into the rotor, negative C_Q, to power output from the rotor. The dotted line refers to the autorotation with hub, and the ordinates of this curve represent the hub torque which was subtracted from the measured torque. The $C_Q - \alpha$ curves also become very steep at higher advance ratios, μ .

3.5.5.3 Tip-Path Plane Angle of Attack - Figure 13 shows the rotor plane angle of attack, α_R , plotted against α for zero tip drag and for a blade pitch of $\theta = -1.5°$. The $\alpha_R - \alpha$ curves increase their slope with μ, indicating a high sensitivity to small α changes.

3.5.3.4 <u>C_T, α, and α_R As Functions of μ</u> - Figure 14 shows C_T α, and α_R plotted against μ for $\Theta = -1.5°$ in autorotation. The flat $\alpha - \mu$ curve for higher μ again indicates the unstable character of these conditions. $(\alpha_R - \alpha)$ is the flapping angle of the blades which is quite moderate for $\Theta = -1.5°$.

3.5.3.5 <u>Drag, Lift, and Lift-to-Drag Ratio A Function of μ</u> - Figure 15 shows the lift to drag ratio, L/D, (called L'/D" in Section 3.5.2) the lift coefficient, C_L; and the drag coefficient, C_D, of the rotor without hub plotted against advance ratio, μ, for $\Theta = -1.5°$ in autorotation. The increasing L/D values and the decreasing C_L values with higher advance ratios indicate that from a point of view of performance at high speed large advance ratios are desirable.

3.5.3.6 <u>Torque Coefficient For Various Blade Pitch Angles</u> - Figure 16 shows the torque coefficient, C_Q plotted against α for various blade pitch angles, Θ, and for an advance ratio of $\mu = 1.5$. Note that a <u>decrease</u> in blade pitch in this region increases the decelerating torque, which is opposite to the effect of blade pitch changes in the helicopter flight condition. The rotor is less sensitive to α changes (more stable) at lower blade pitch angles.

3.5.3.7 <u>Effect of Blade Angle on C_T, α, and α_R</u> - Figure 17 shows the effect of blade pitch angle, Θ, on thrust coefficient, C_T, on α, and on α_R for $\mu = 1.5$, in autorotation. The flapping angle $(\alpha_R - \alpha)$ is zero for $\Theta = -2.5°$ and increases rapidly with negative Θ.

3.5.3.8 Effect of Blade Angle on (L/D), C_L, and C_D - Figure 18 shows the effect of blade pitch angle, Θ, on lift-to-drag ratio, L/D, on C_L, and on C_D. While C_L and C_D decrease with negative Θ, the L/D ratio has a flat optimum at about $\Theta = -1.5°$.

3.5.4 Tests With the Automatic Rotor Attitude Control - Because of several delays and required modifications of the test equipment the governor tests were reduced somewhat in scope. The tests were made for only one blade pitch setting, $\Theta = 0°$, and for zero torque. Advance ratios of 0.5, 1.0, 1.5, and 2.0 were investigated.

It was found that the RPM oscillations damped out after two to three oscillation periods after a sudden one degree rotor attitude disturbance. But while the oscillations damped out quickly, the maximum RPM error was much too high (+ 25% for + 1° attitude change and -[illegible]% for -1° attitude change).

3.5.5 Experimental Data - The complete data accumulated during the second series of tests is presented in Section 7.0.

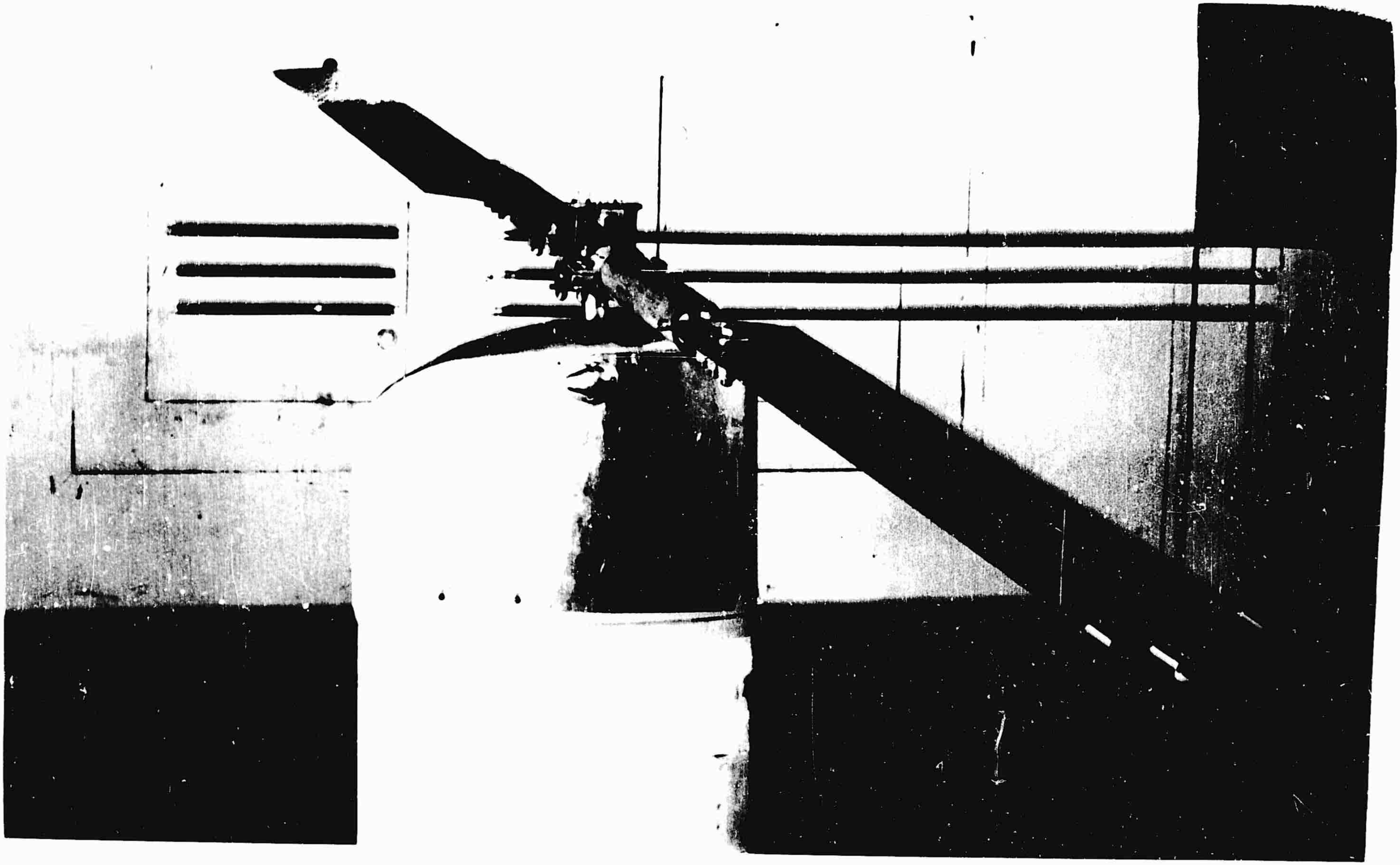
4.0 CONCLUSIONS

The second series of tests confirmed the results of the first series that autorotation of the VTO rotor at high advance ratios is very advantageous from a point of view of blade losses. The drag coefficient of the blade without hub, referred to the rotor disc area, is only 0.001 at $\mu = 2.0$. This means that a 50-feet rotor, suitable for a 20,000 pound rotor-fixed wing aircraft, would only represent the equivalent of two square feet parasite drag area. This drag is not totally parasitic because the rotor also produces a lift force up to 13 times greater than this drag. The over-sensitivity of all rotor characteristics with respect to rotor angle of attack changes should be mitigated because otherwise even moderate gusts would cause excessive flapping of the blades. These tests have been extended up to an advance ratio of 2.5, which corresponds to a flight speed of 390 mph with a tip speed at the advancing blade of 800 ft./sec. or to 340 mph with a tip speed of 700 ft./sec.

5.0 REFERENCES

1. Mead, R. E. The Results of an Analytical Study of the Aerodynamic Rotor Characteristics at High Tip-Speed Ratios. MAC Report No. 1686, 12 May 1950.

6.0 PHOTOGRAPHS AND SELECTED TEST RESULT GRAPHS



Report No. 1975
Negative No.
D4E-19772-490-9

Figure 1
Side View of Model as Installed in the Wind Tunnel
(First Series of Tests)

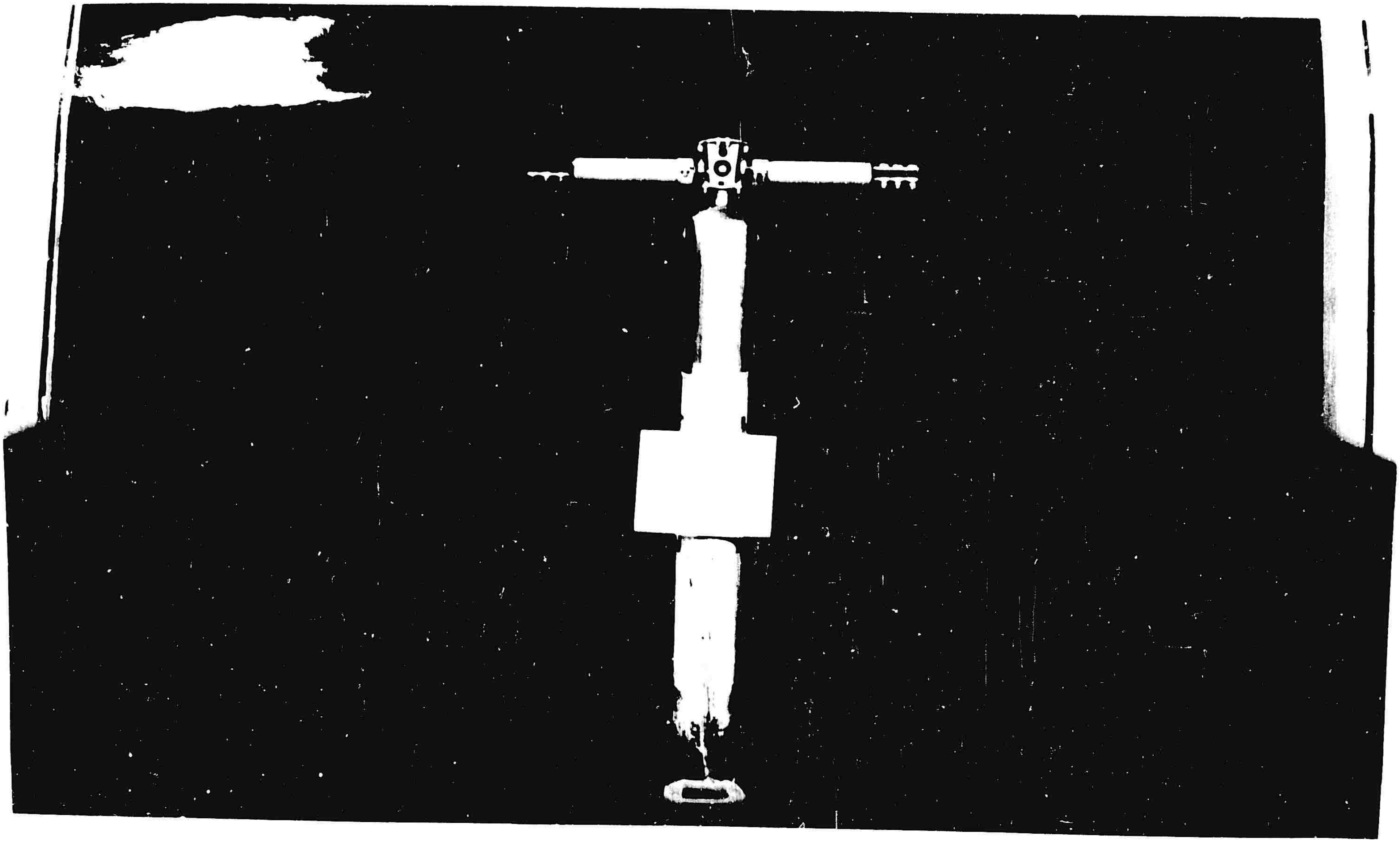
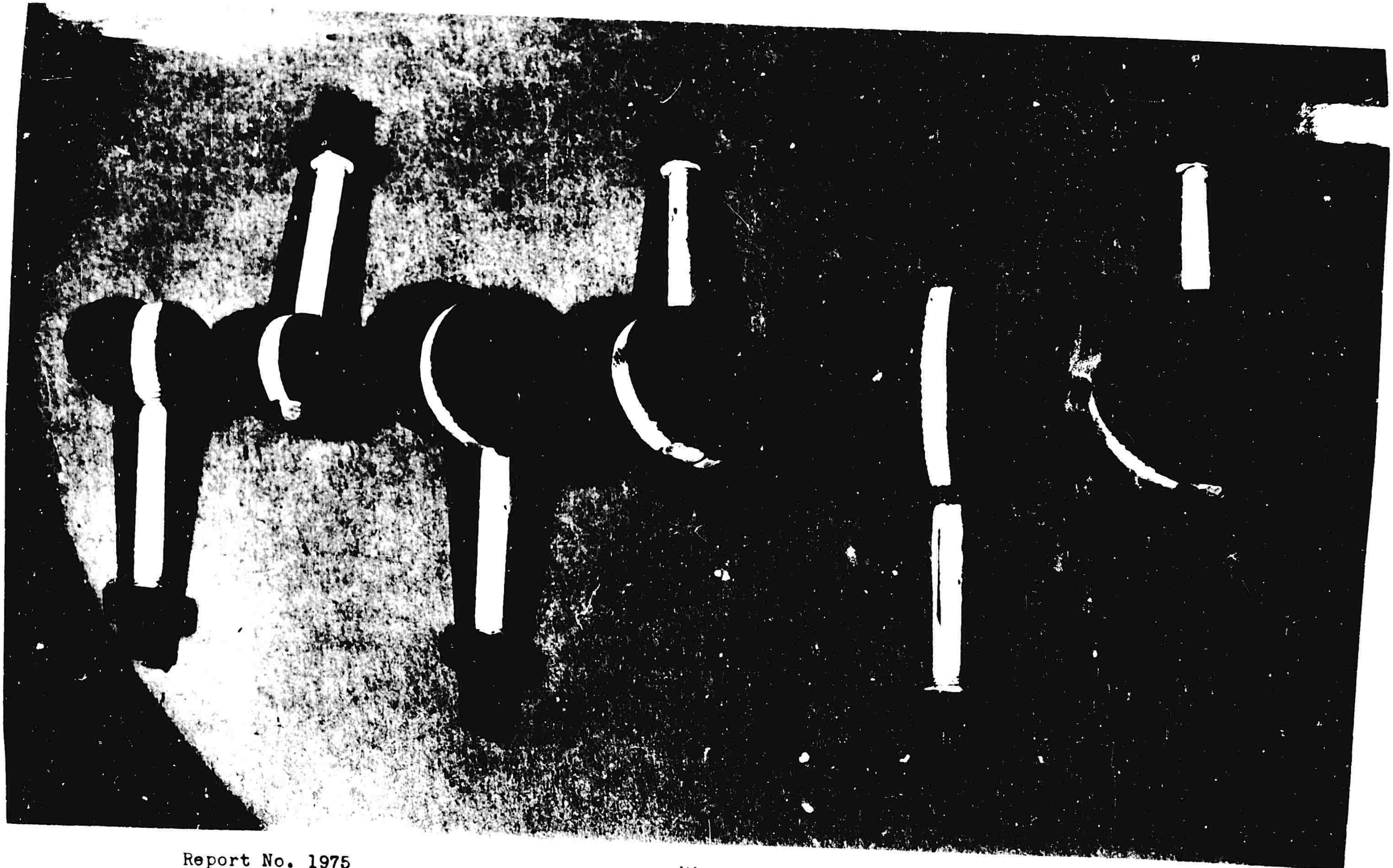


Figure 2

Report No. 1975
Negative No.
D4E-19772-490-8

Front View of Model as Installed in the Wind Tunnel
(First Series of Tests)

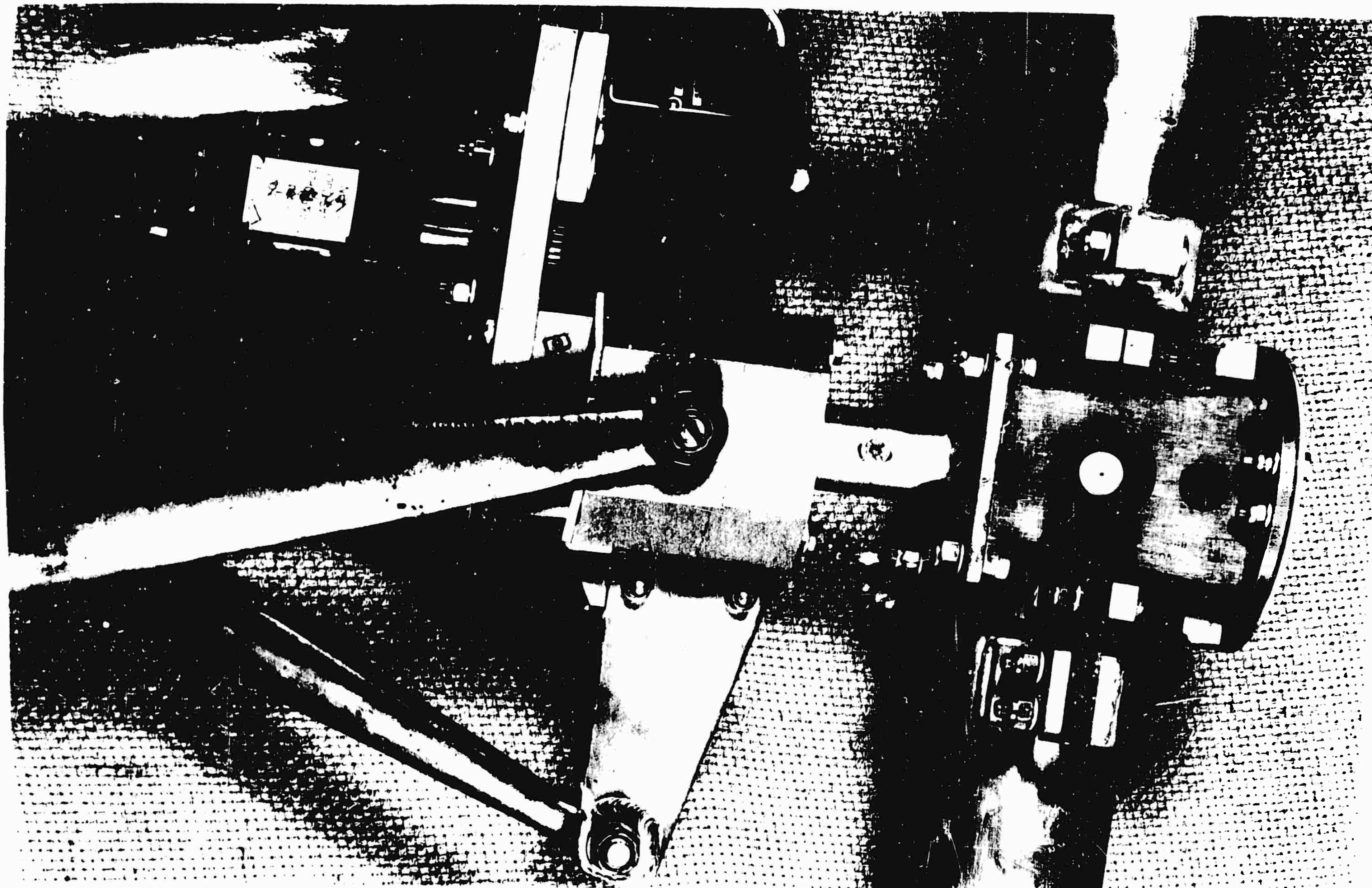
CONFIDENTIAL



Report No. 1975
Negative No.
D4H-13893

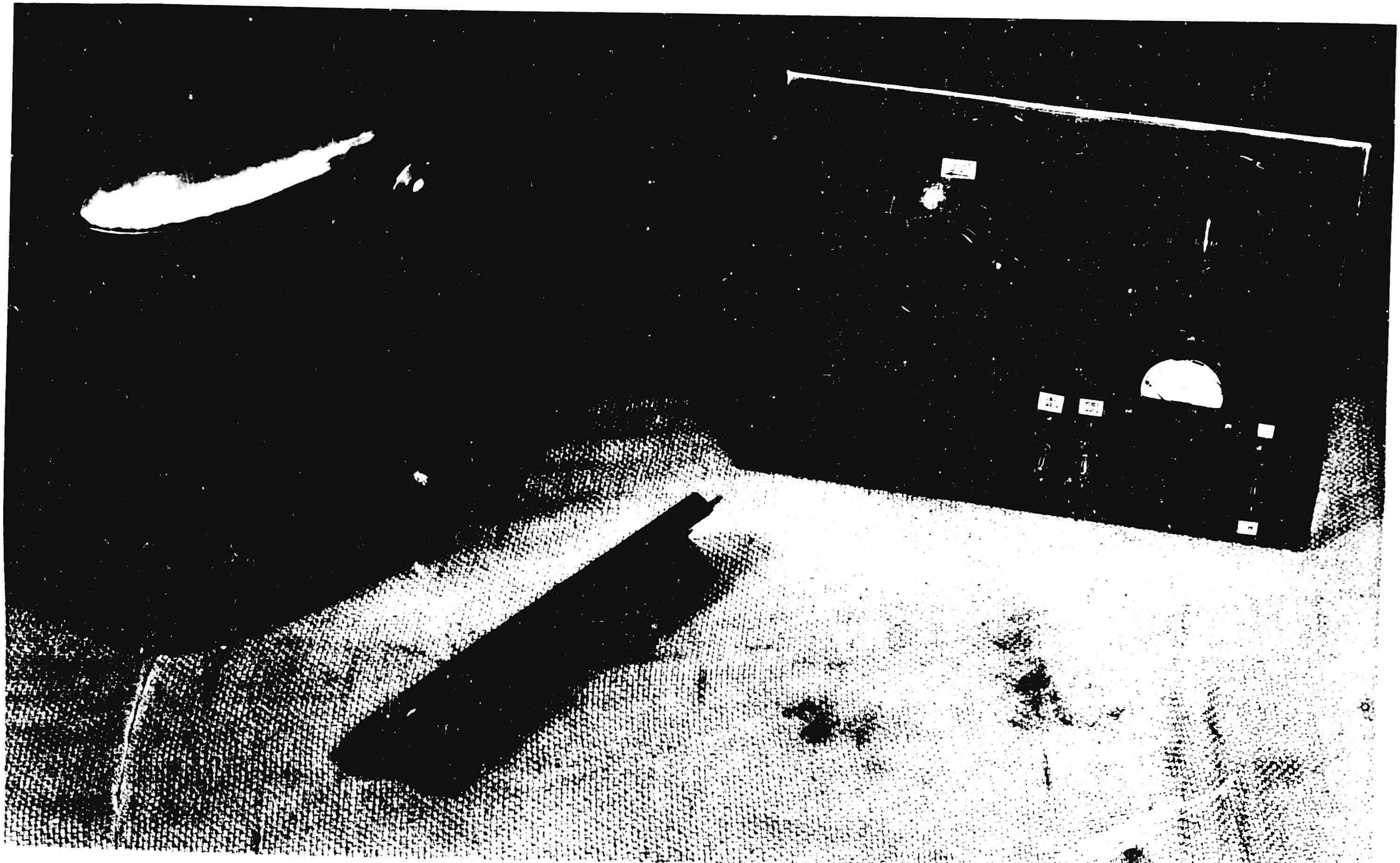
Figure 3
Blade Tip Spheres

CONFIDENTIAL



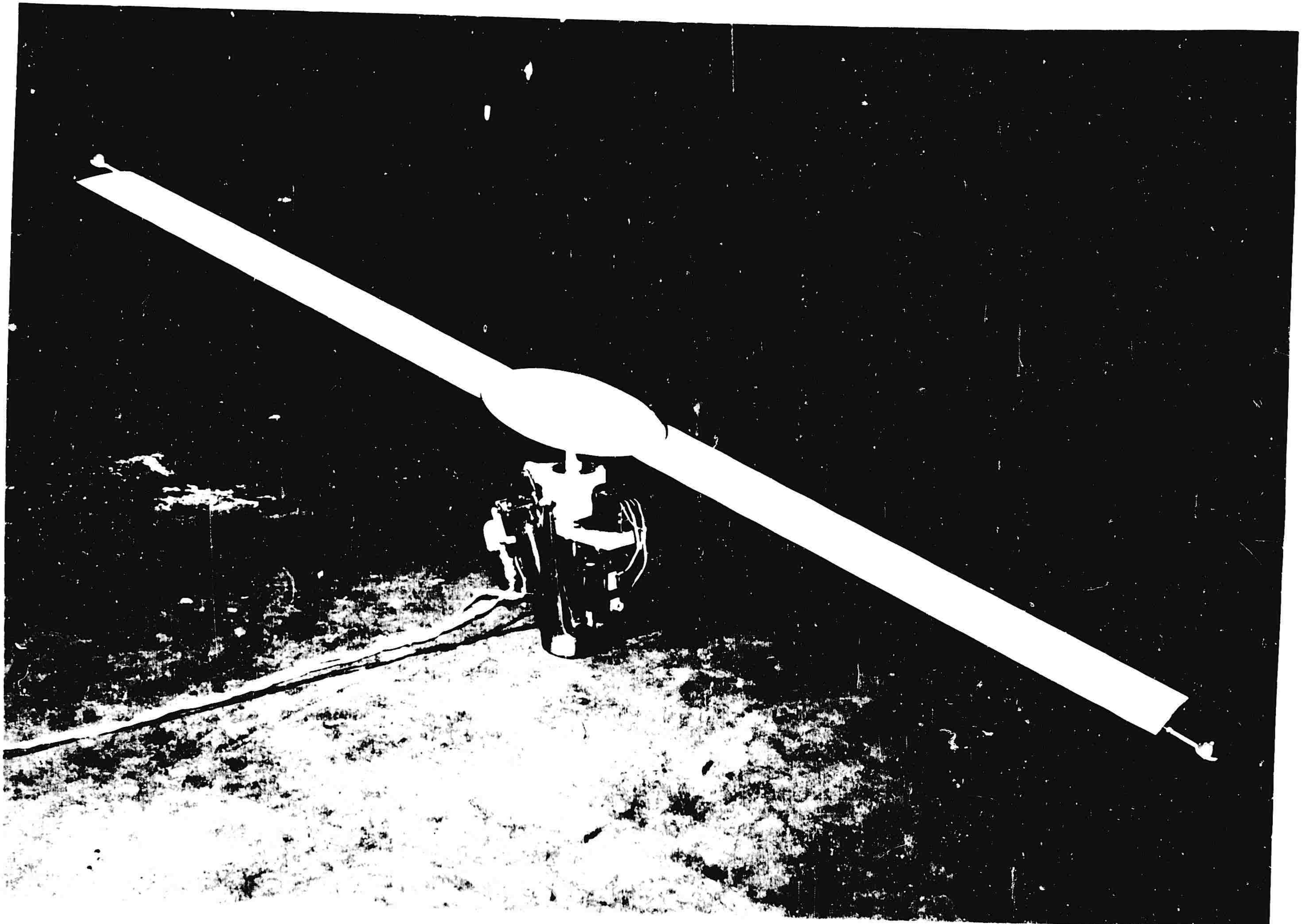
Report 1975
Negative No.
D4H-13896

Figure 4
Center Portion of Model Including Fork and Pitch Arm of Tunnel Equipment
(First Series of Tests)



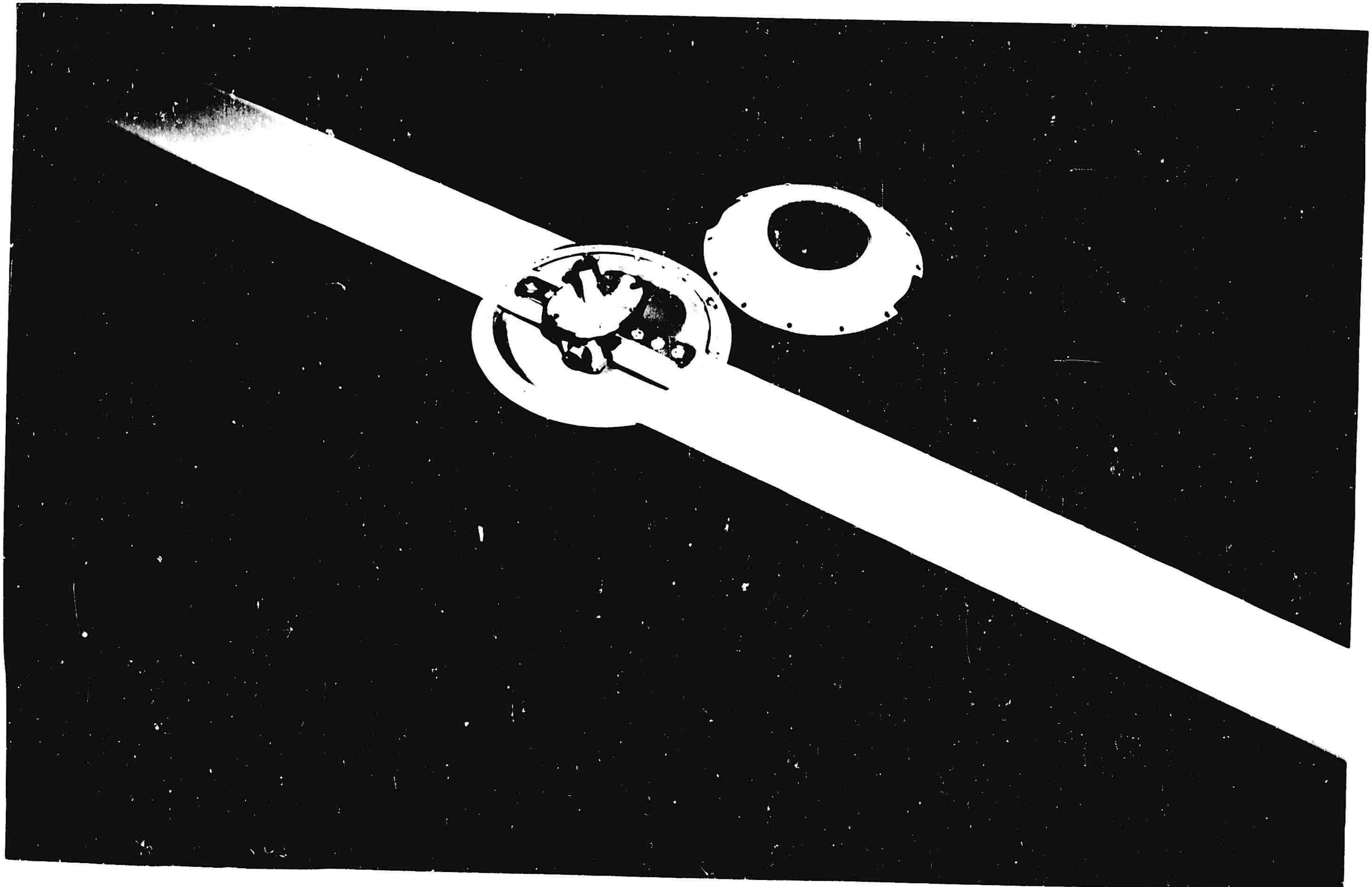
Report No. 1975
Negative No.
D4H-13895

Figure 5
Upper Fairing, Central Panel for Electric Motor For Model, and Blade Pitch Measuring Fixture



REPORT 1975
NEGATIVE D4E-15435

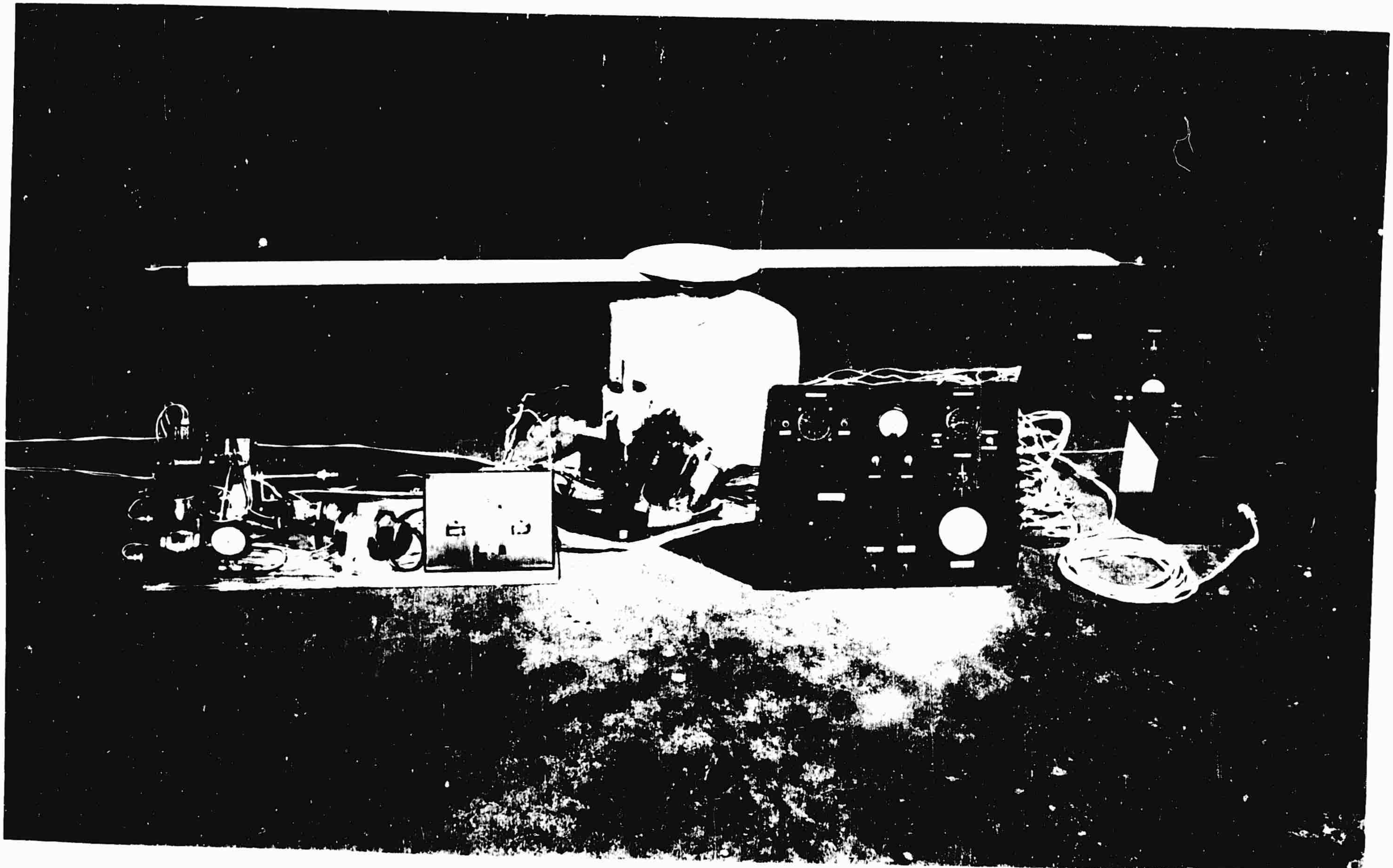
FIGURE 6 - REVISED ROTOR MODEL WITH HUB-FAIRING
(SECOND SERIES OF TESTS)
CONFIDENTIAL



Report No. 1975
Negative No.
D4E-15436

Figure 7
Revised Rotor Model With One Section of Hub Fairing Removed
(Second Series of Tests)

CONFIDENTIAL



Report No. 1975
Negative No.
D45-15438

Figure 8
Revised Rotor Model With Governor and Control Panels
(Second Series of Tests)

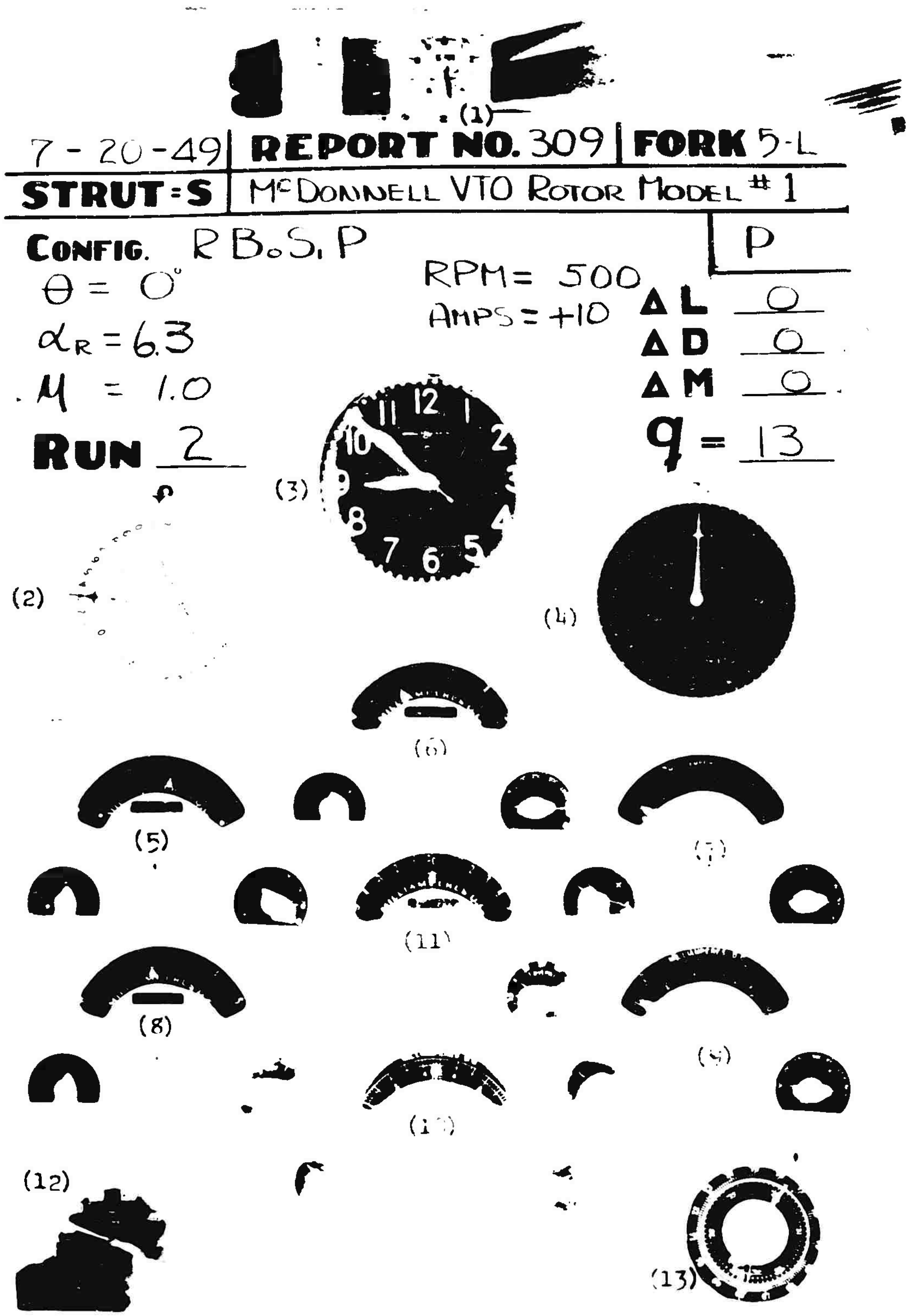


FIGURE 9. TYPICAL PHOTO-PANEL PHOTOGRAPH

CONFIDENTIAL

Report No. 1975
Negative No.
D4H-13894

Figure 10
Device for Measuring the Attitude of the Rotor Tip Path Plane

CONFIDENTIAL

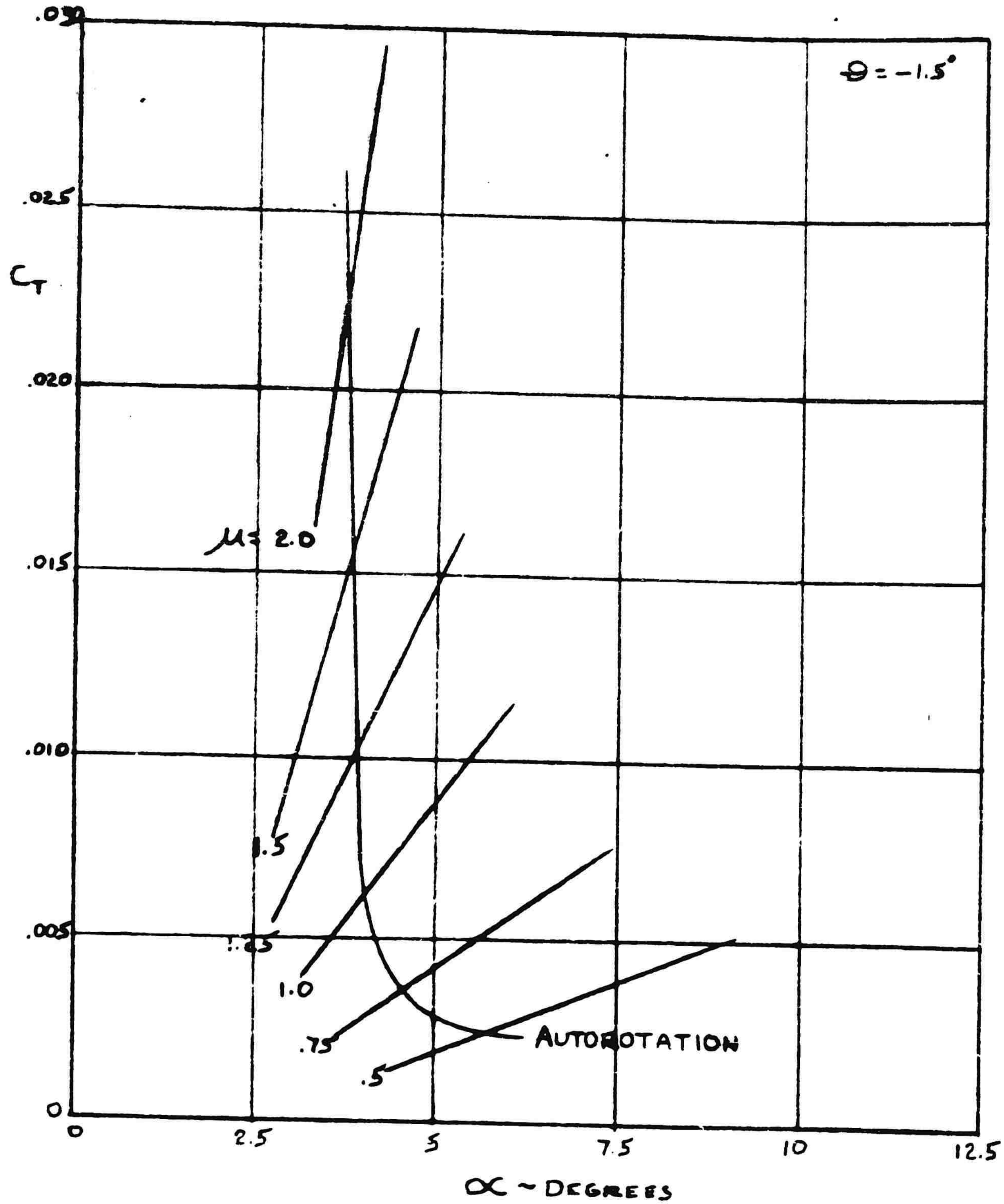


FIGURE 11

THRUST COEFFICIENT C_T PLOTTED AGAINST α FOR ZERO TIP DRAG AND FOR BLADE PITCH $\theta = -1.5°$

CONFIDENTIAL

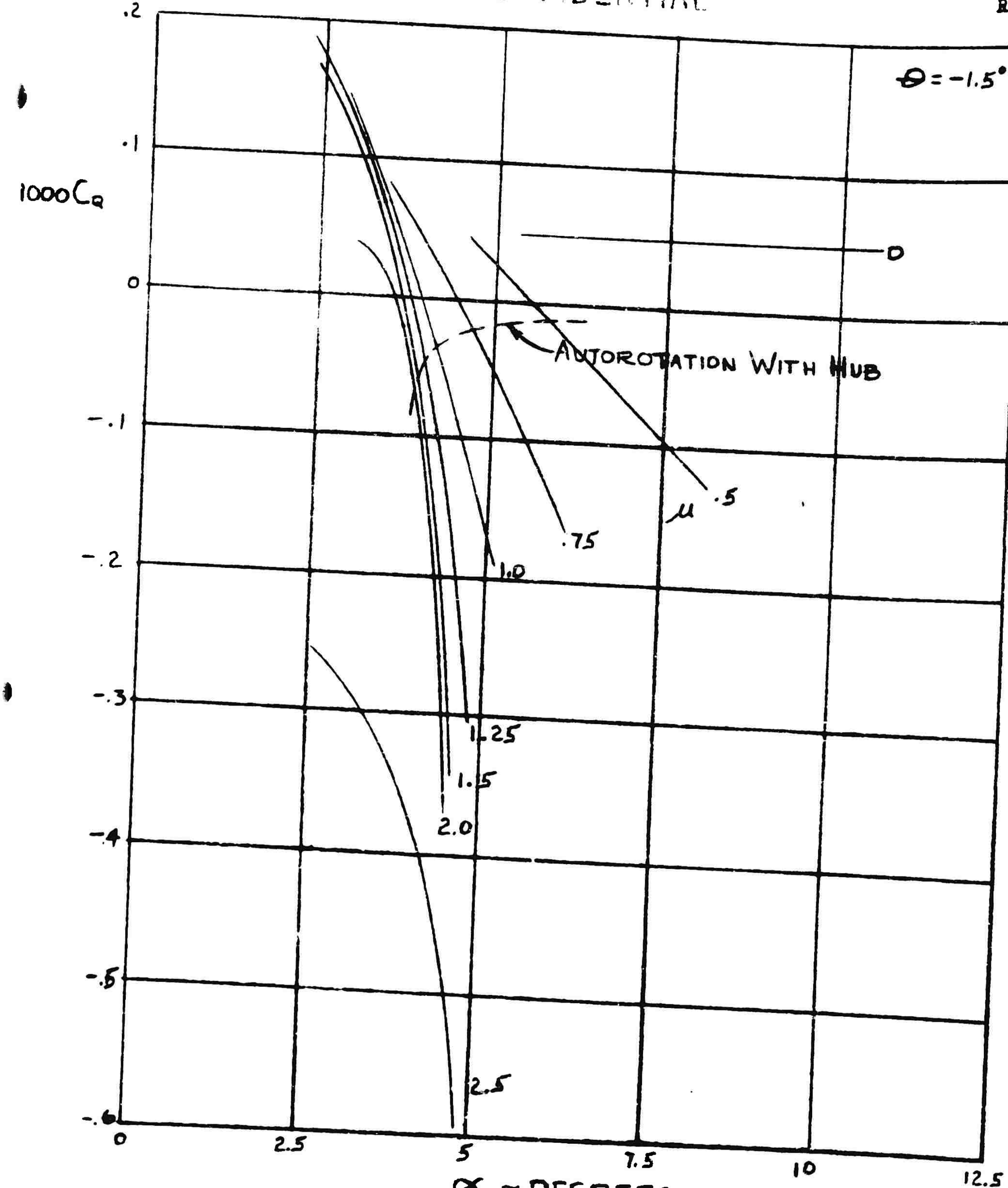


FIGURE 12

TORQUE COEFFICIENT C_Q PLOTTED AGAINST α FOR ZERO TIP DRAG AND BLADE PITCH $\theta = -1.5°$

CONFIDENTIAL

CONFIDENTIAL

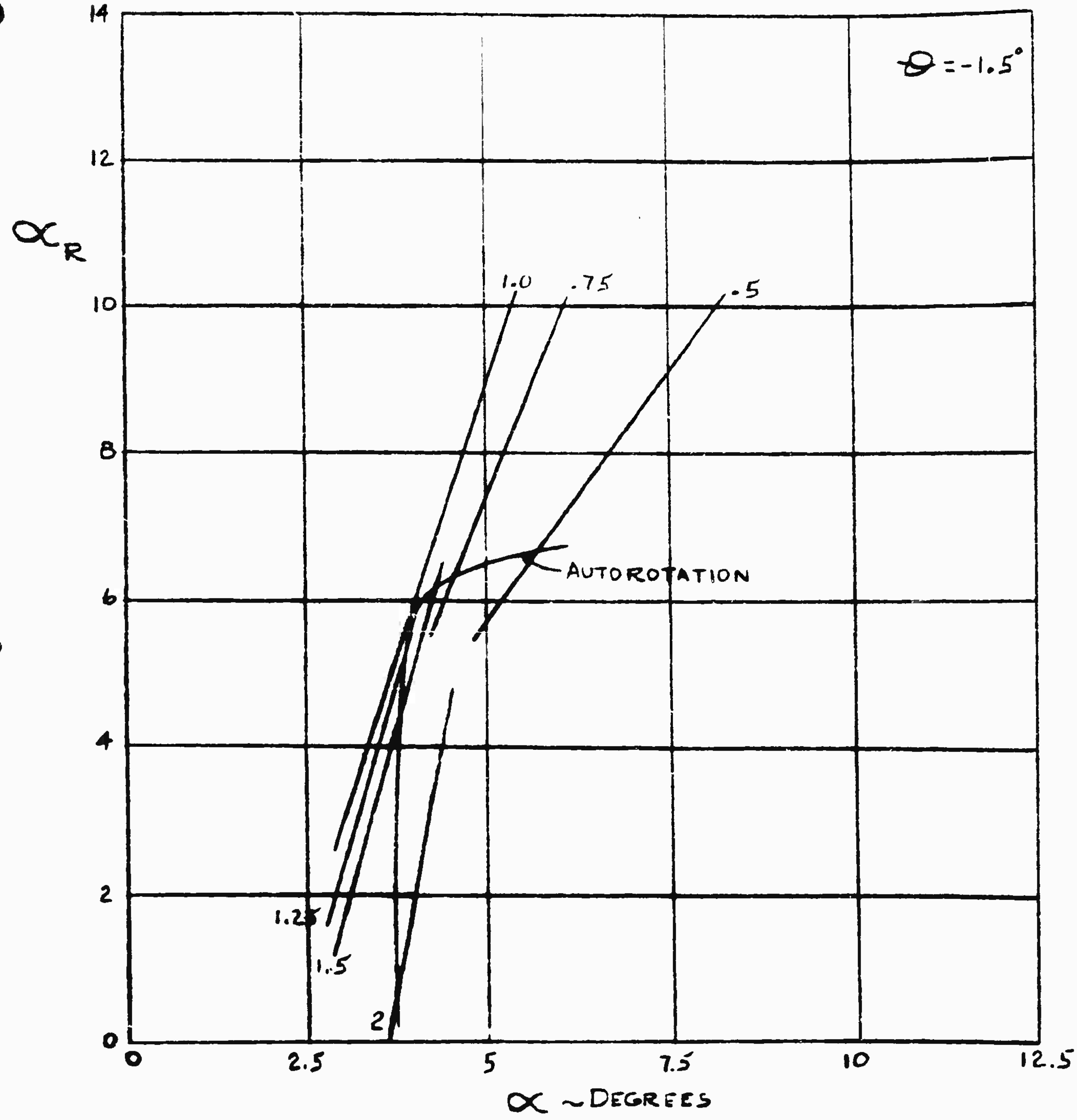


FIGURE 13

ROTOR PLANE POSITION α_R PLOTTED AGAINST α FOR ZERO TIP DRAG AND BLADE PITCH $\theta = -1.5°$

CONFIDENTIAL

CONFIDENTIAL

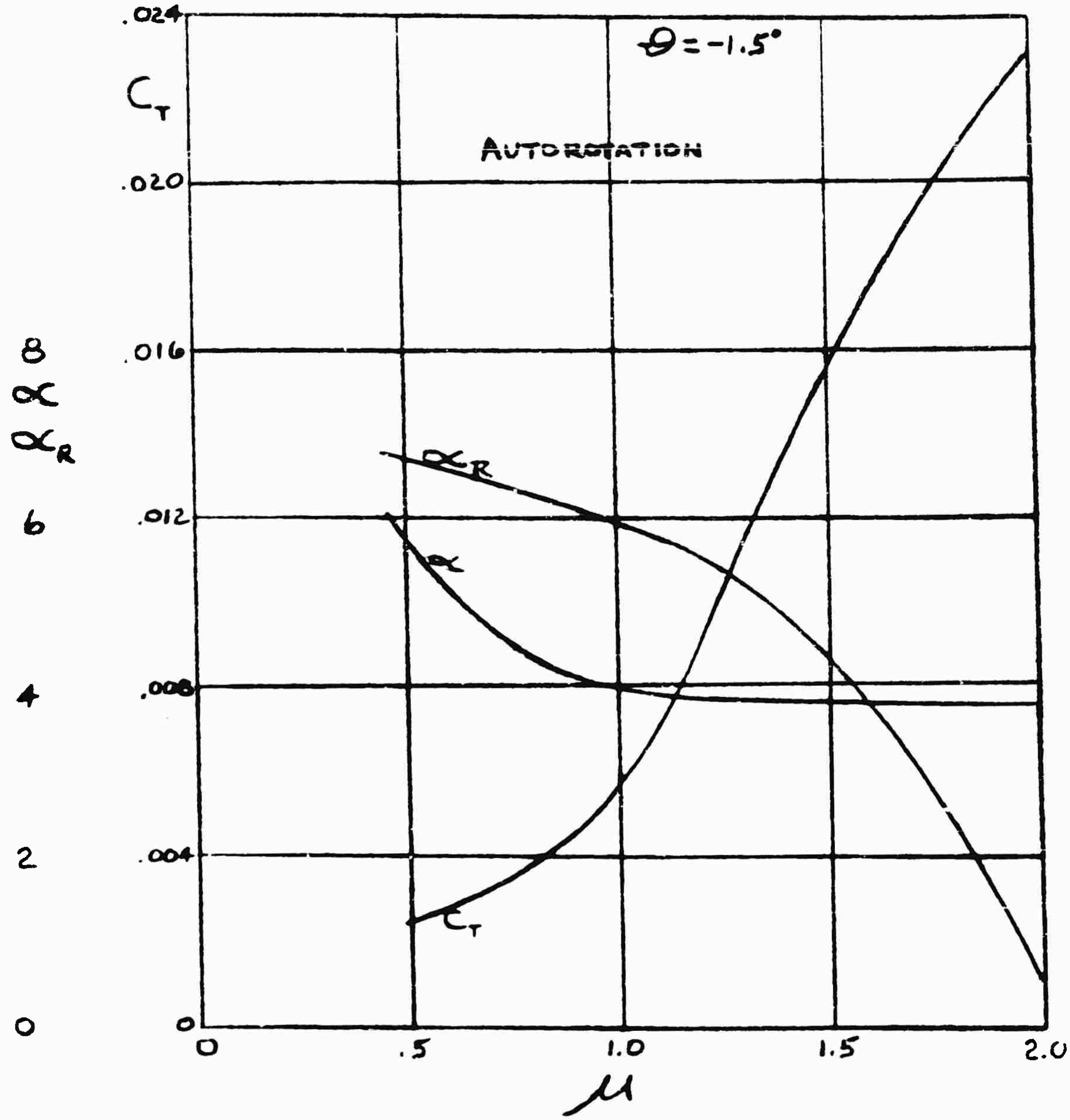


FIGURE 14

THRUST COEFFICIENT C_T, POSITION OF CONTROL PLANE α AND POSITION OF PLANE OF ROTATION α_R PLOTTED AGAINST ADVANCE RATIO μ FOR BLADE PITCH $\theta = -1.5°$ IN AUTOROTATION

CONFIDENTIAL

CONFIDENTIAL

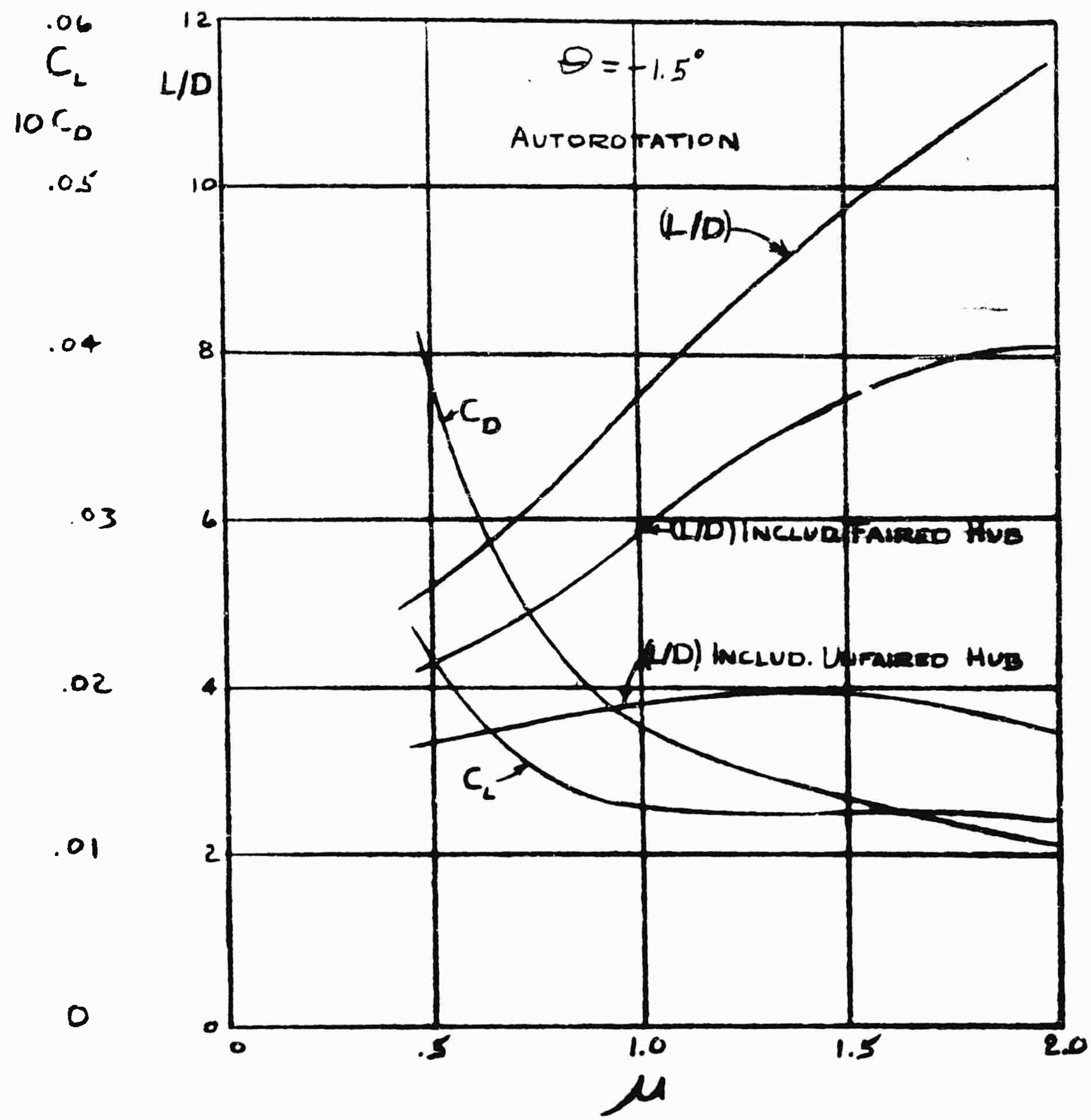


FIGURE 15

LIFT TO DRAG RATIO (L/D), LIFT COEFFICIENT C_L AND DRAG COEFFICIENT C_D PLOTTED AGAINST ADVANCE RATIO μ FOR BLADE PITCH $\theta = -1.5°$ IN AUTOROTATION

CONFIDENTIAL

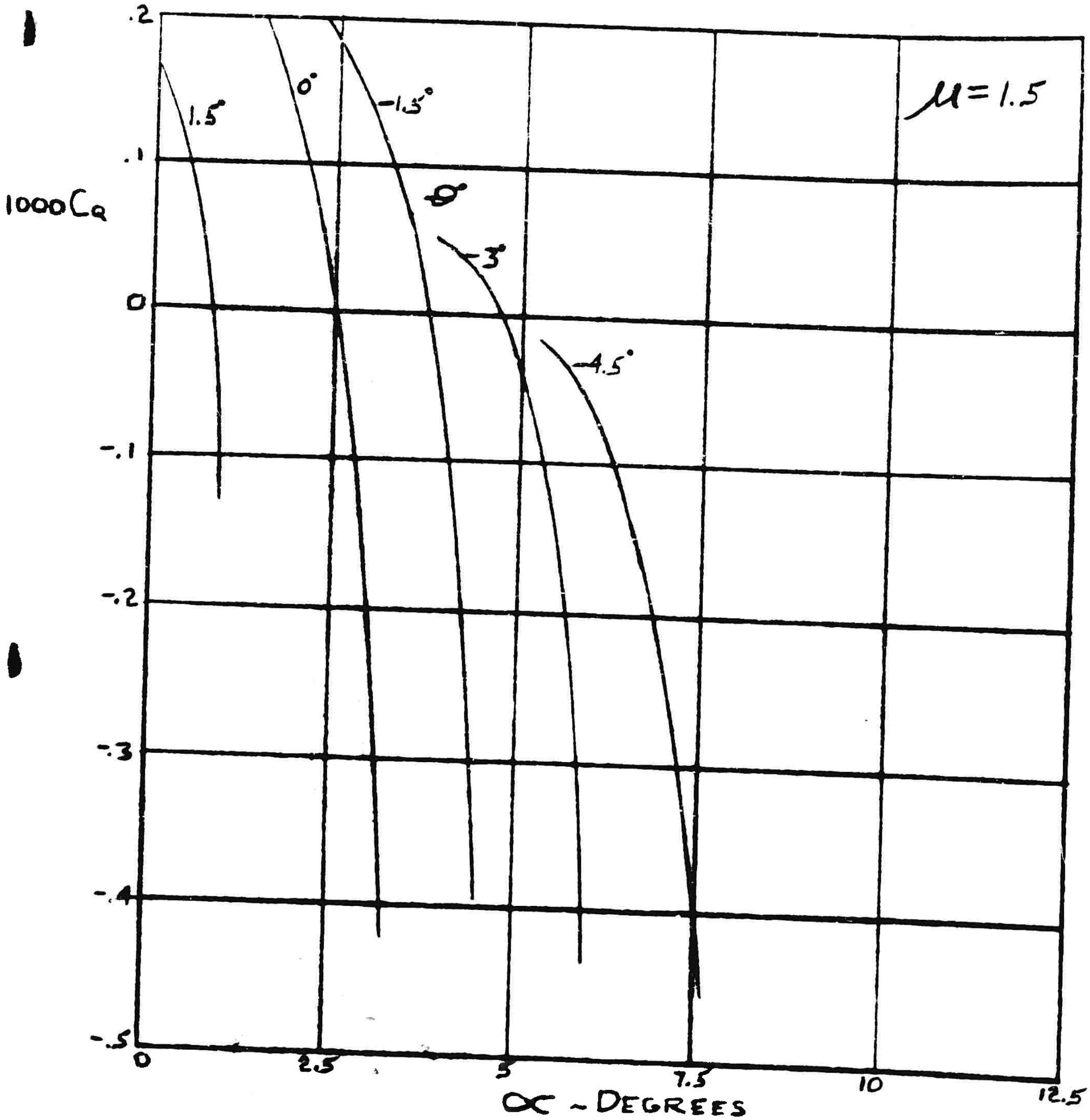
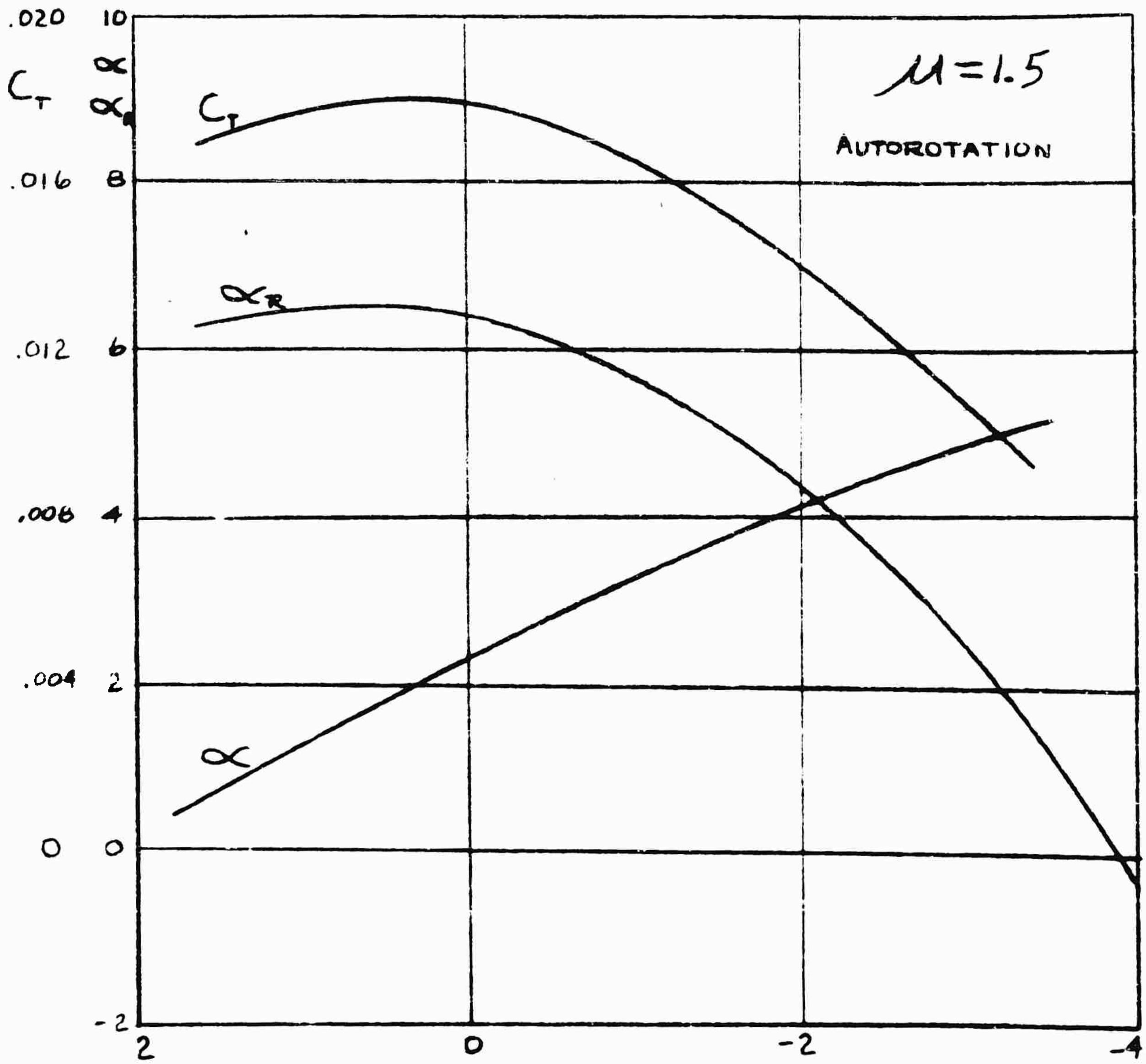


FIGURE 16

TORQUE COEFFICIENT C_Q PLOTTED AGAINST α FOR ZERO TIP DRAG AND ADVANCE RATIO μ = 1.5

CONFIDENTIAL



θ ~ DEGREES

FIGURE 17

THRUST COEFFICIENT C_T , POSITION OF CONTROL PLANE α AND POSITION OF PLANE OF ROTATION α_R PLOTTED AGAINST BLADE PITCH θ FOR ADVANCE RATIO $\mu = 1.5$ IN AUTOROTATION

CONFIDENTIAL

CONFIDENTIAL

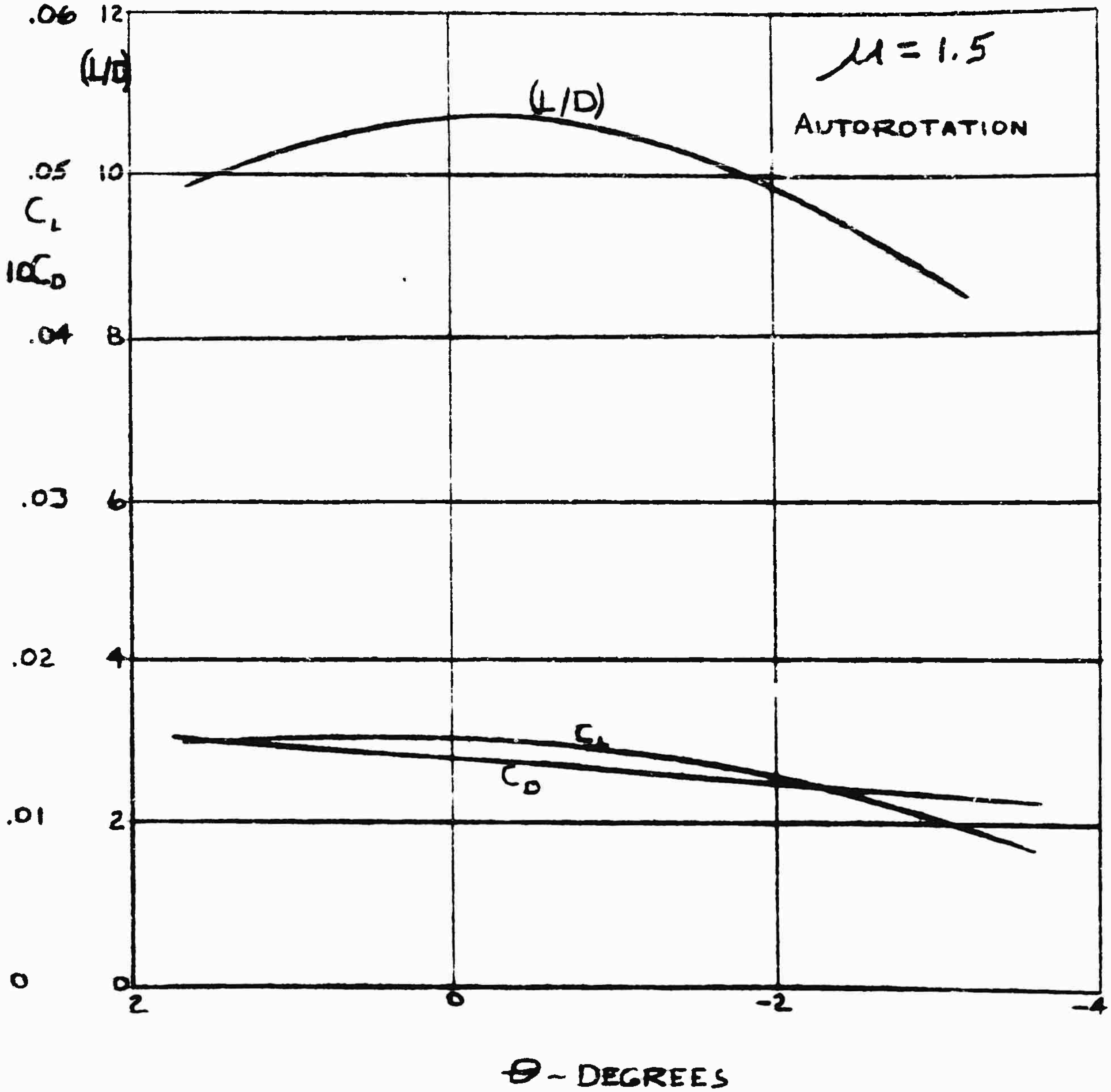


FIGURE 1B

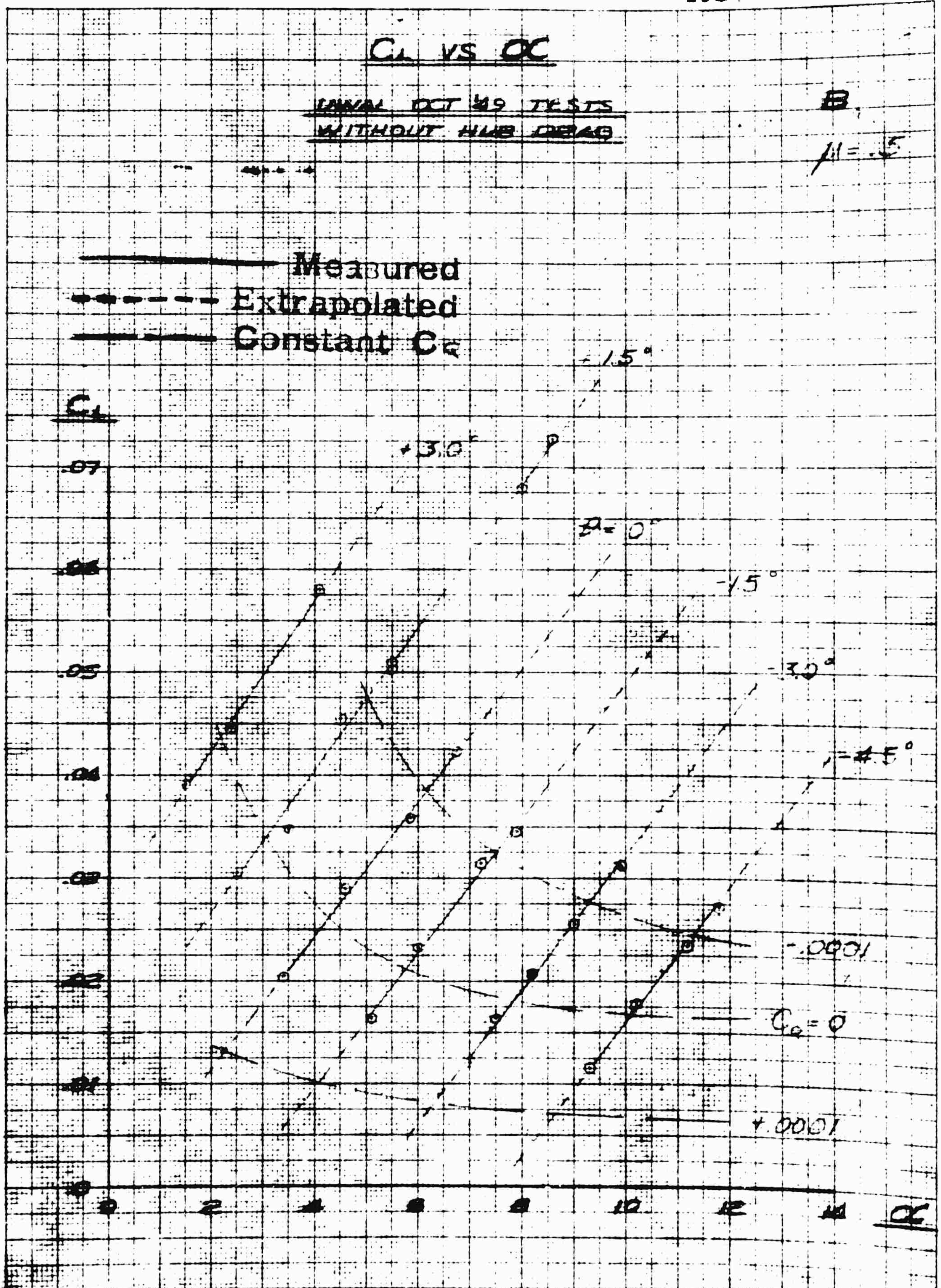
LIFT TO DRAG RATIO (L/D), LIFT COEFFICIENT C_L AND DRAG COEFFICIENT C_D PLOTTED AGAINST BLADE PITCH ANGLE θ FOR ADVANCE RATIO $\mu = 1.5$ IN AUTOROTATION

CONFIDENTIAL

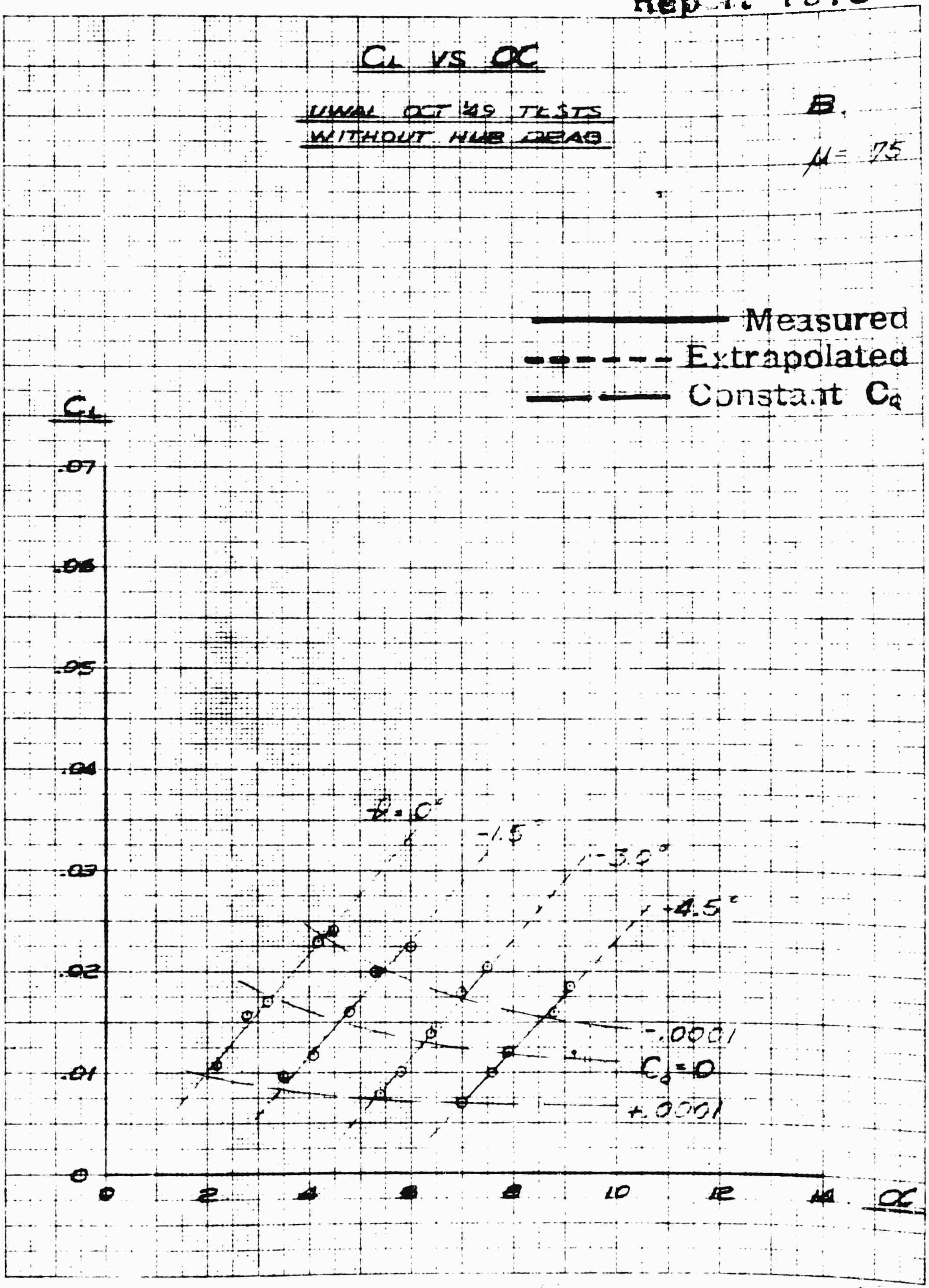
7.0 TEST RESULTS IN GRAPHS

SYMBOLS

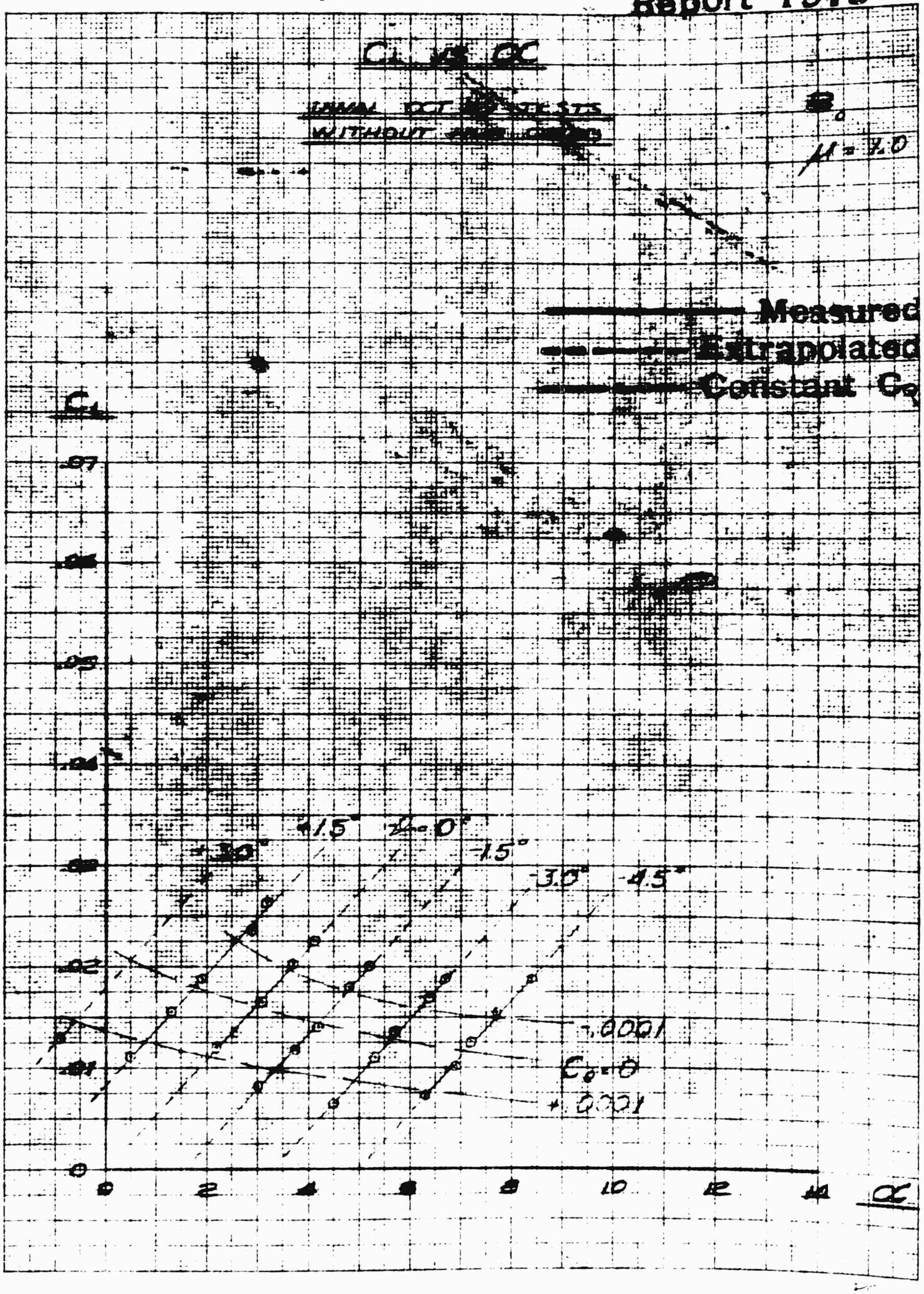
a_1	Longitudinal Tilt of Tip Path Plane
B_0	Configuration Without Tip Balls
B_1	Configuration With Small Tip Balls
B_2	Configuration With Large Tip Balls
C_D	Drag Coefficient
C_L	Lift Coefficient
C_Q	Torque Coefficient
C_T	Thrust Coefficient
D	Drag in Pounds
L	Lift in Pounds
Q	Torque in Foot-Pounds
q	Dynamic Pressure, Lbs./Ft.^{2}
R	Rotor Radius, Feet
(L/D)	Lift to Drag Ratio
α	Rotor Control Plane Angle
θ	Collective Pitch of Rotor Blades
μ	Advance Ratio



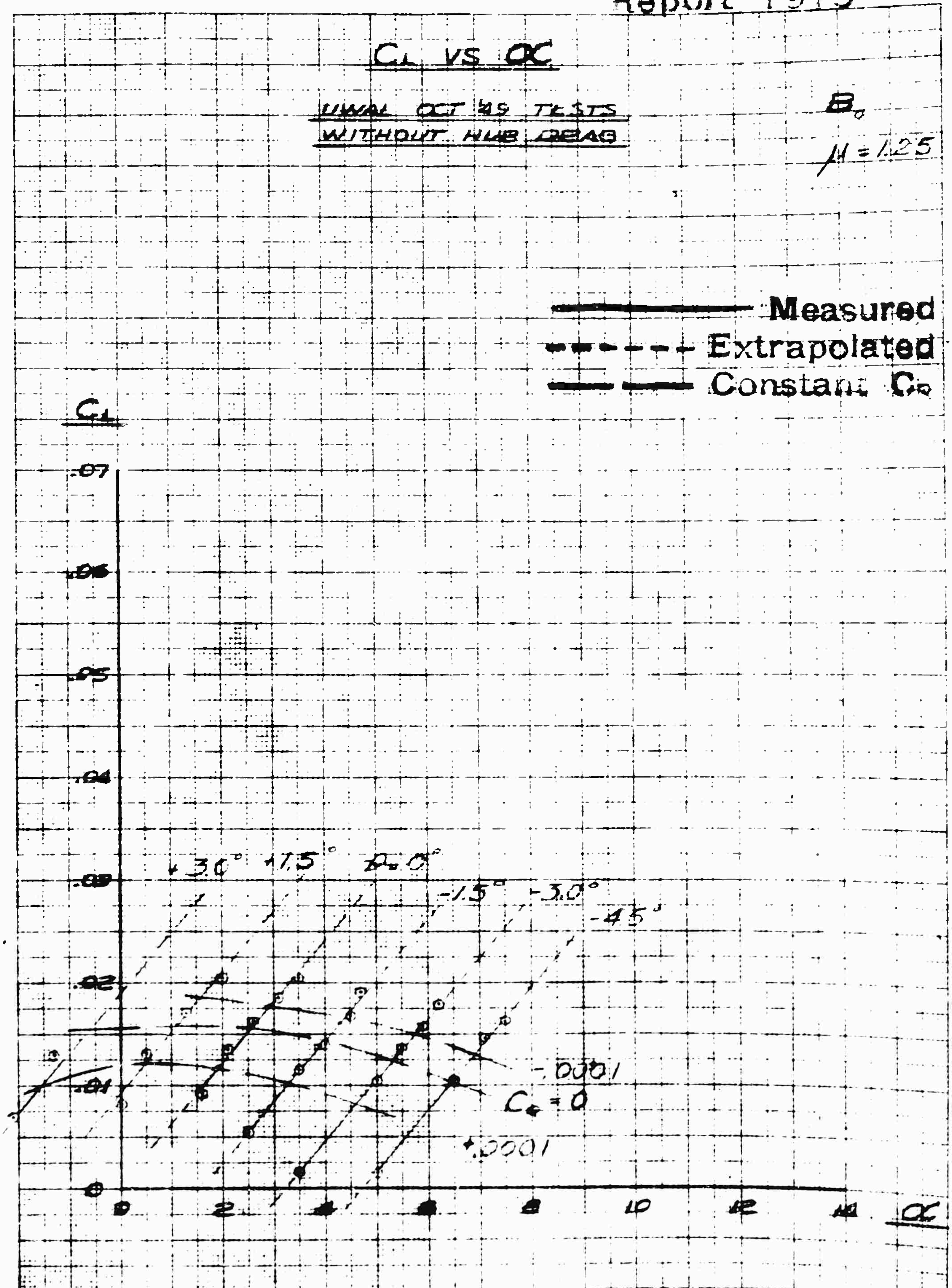
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



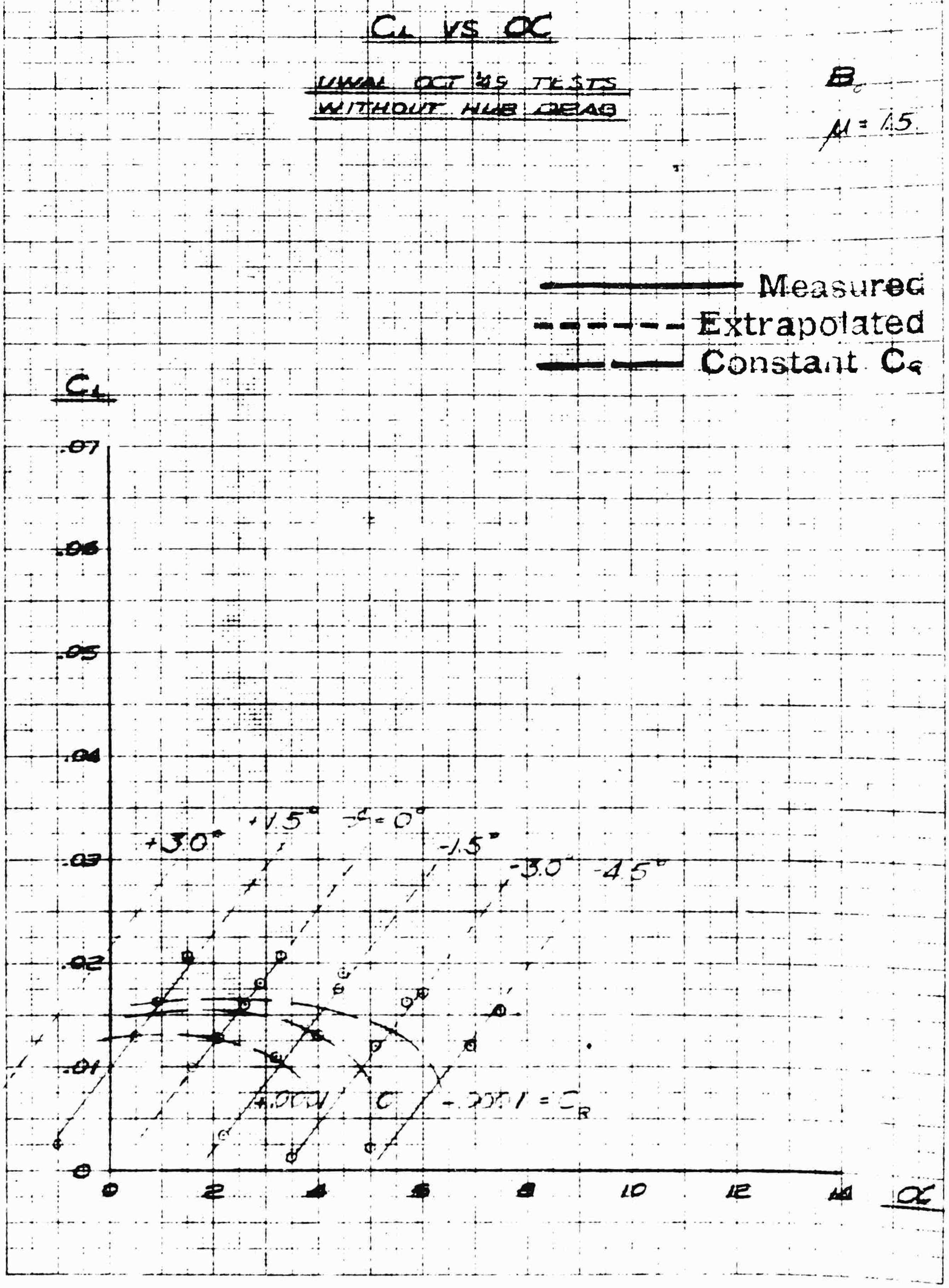
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

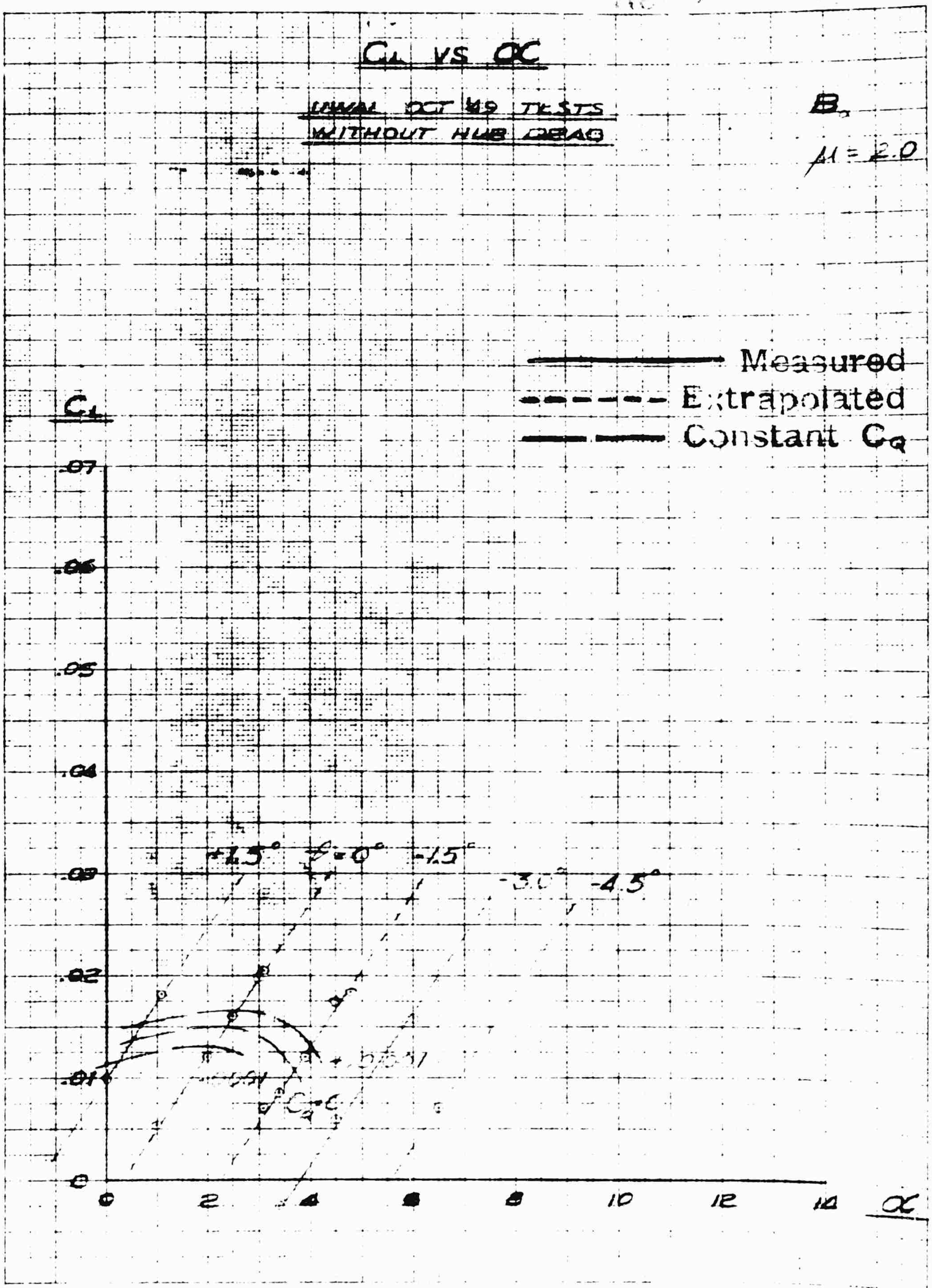


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

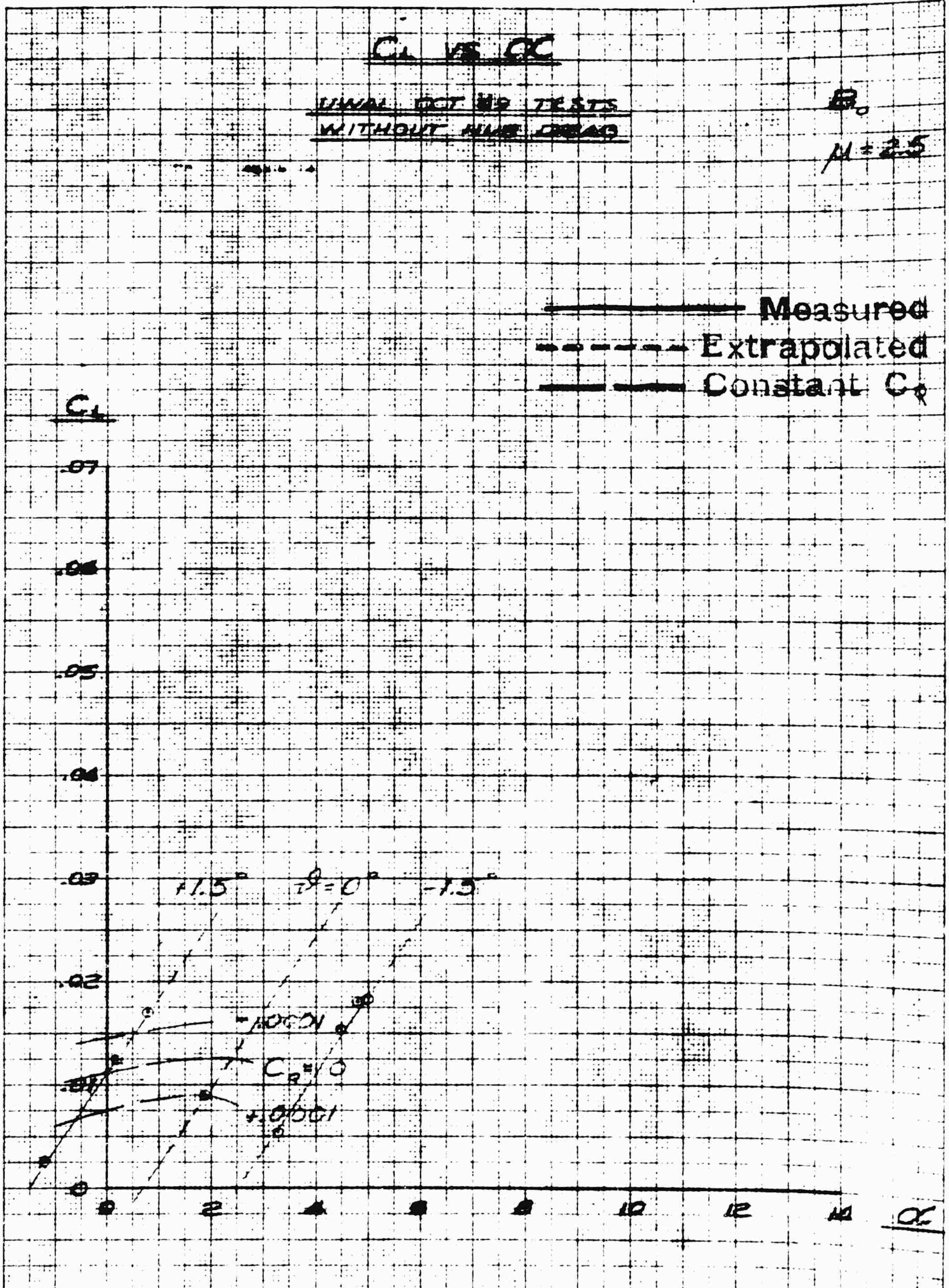


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

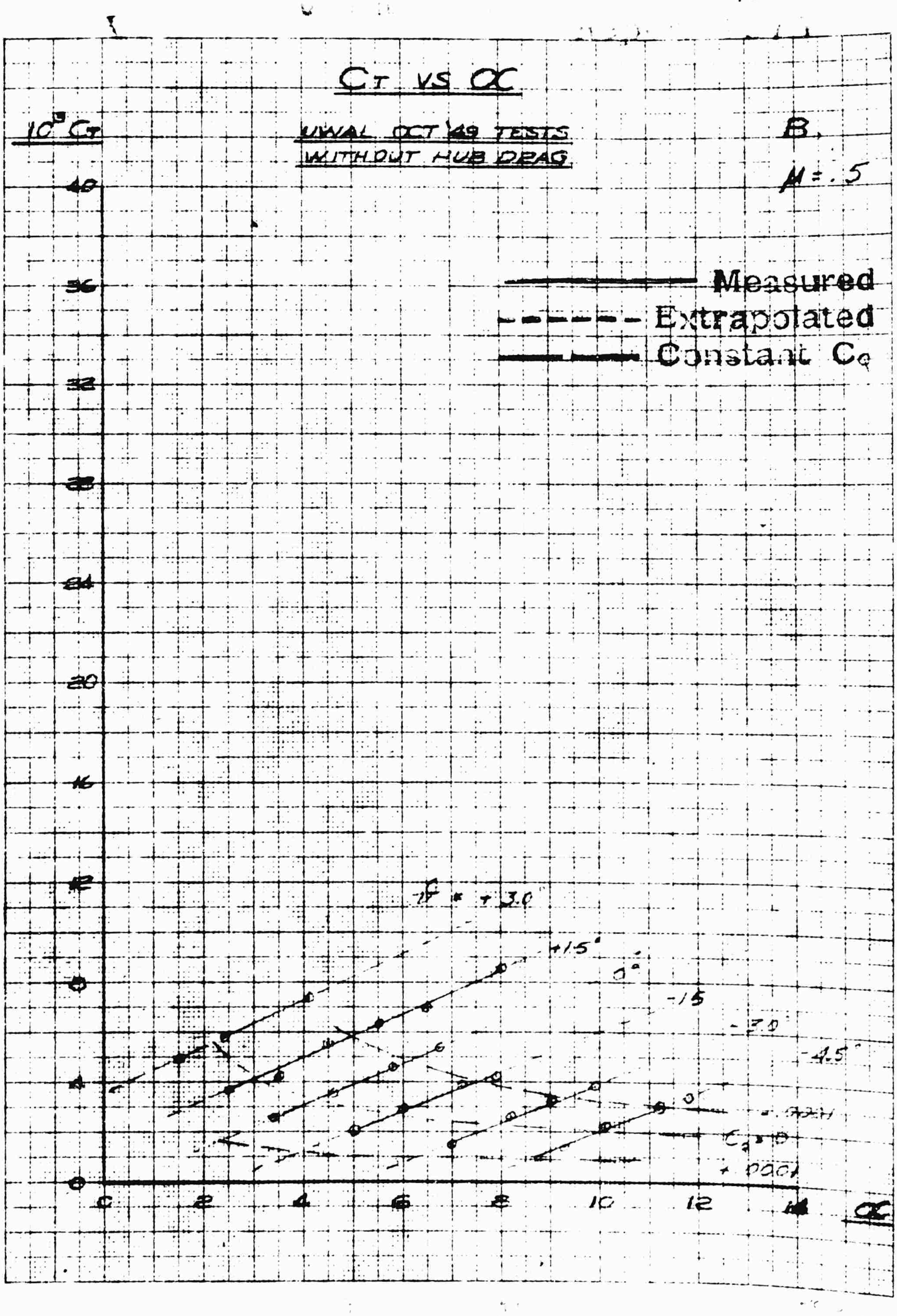

C_L VS α_C
UWAL OCT '45 TESTS
WITHOUT HUB DRAG
B
μ = .45
Measured
Extrapolated
Constant C_R
C_L
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
α_C
+3.0°
+1.5°
θ = 0°
-1.5°
-3.0°
-4.5°
+.0001
0
-.0001 = C_R



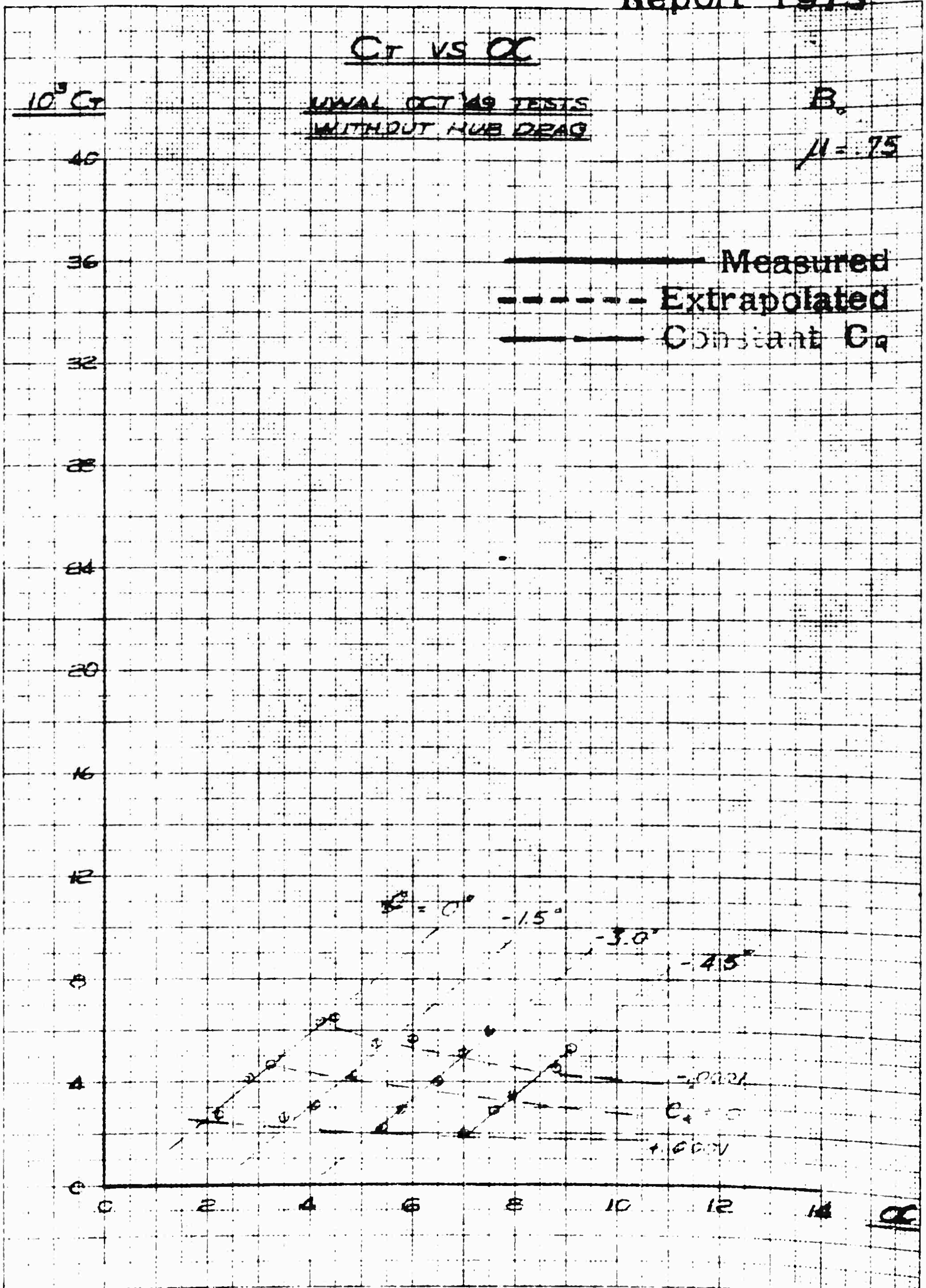
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

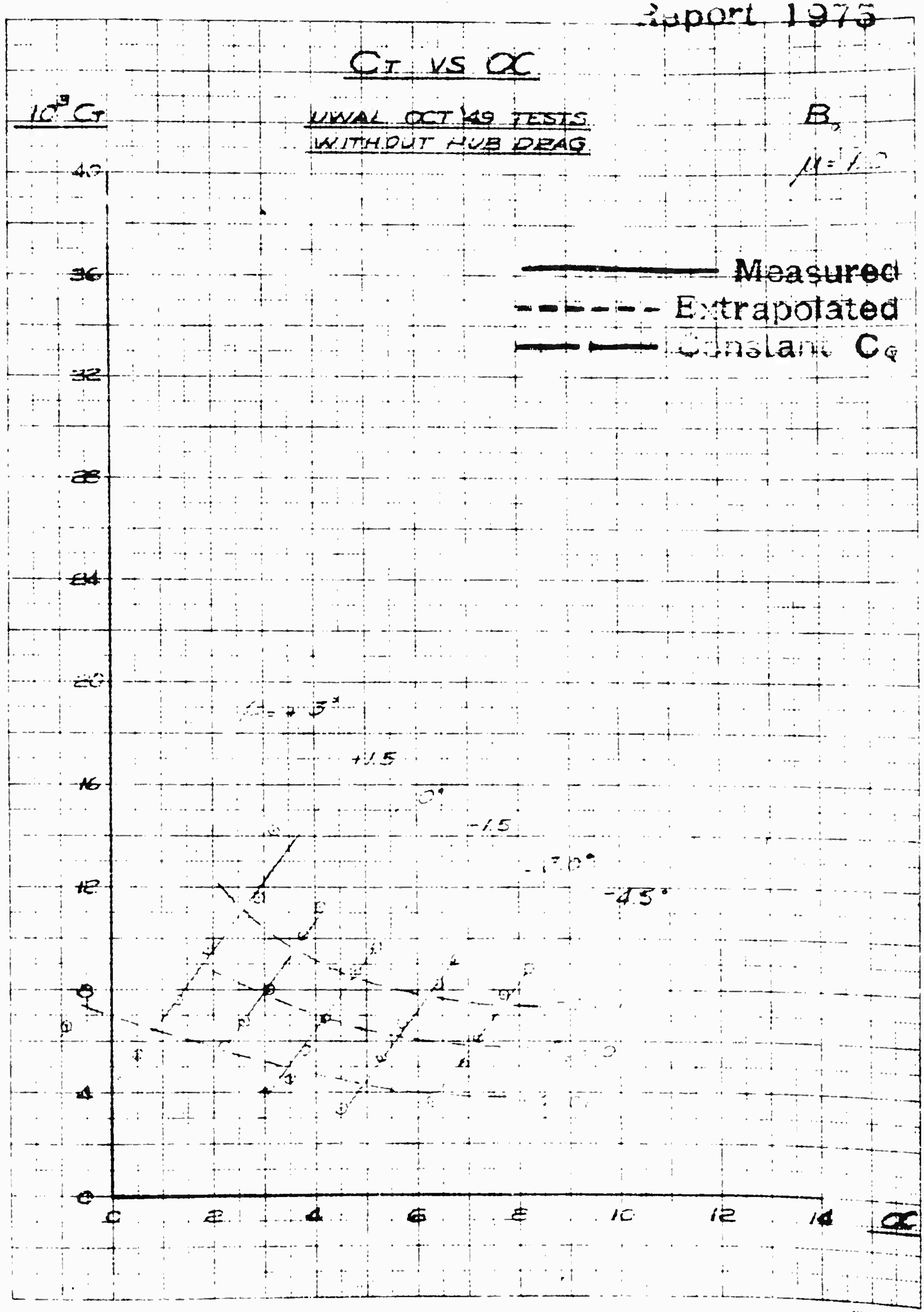


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

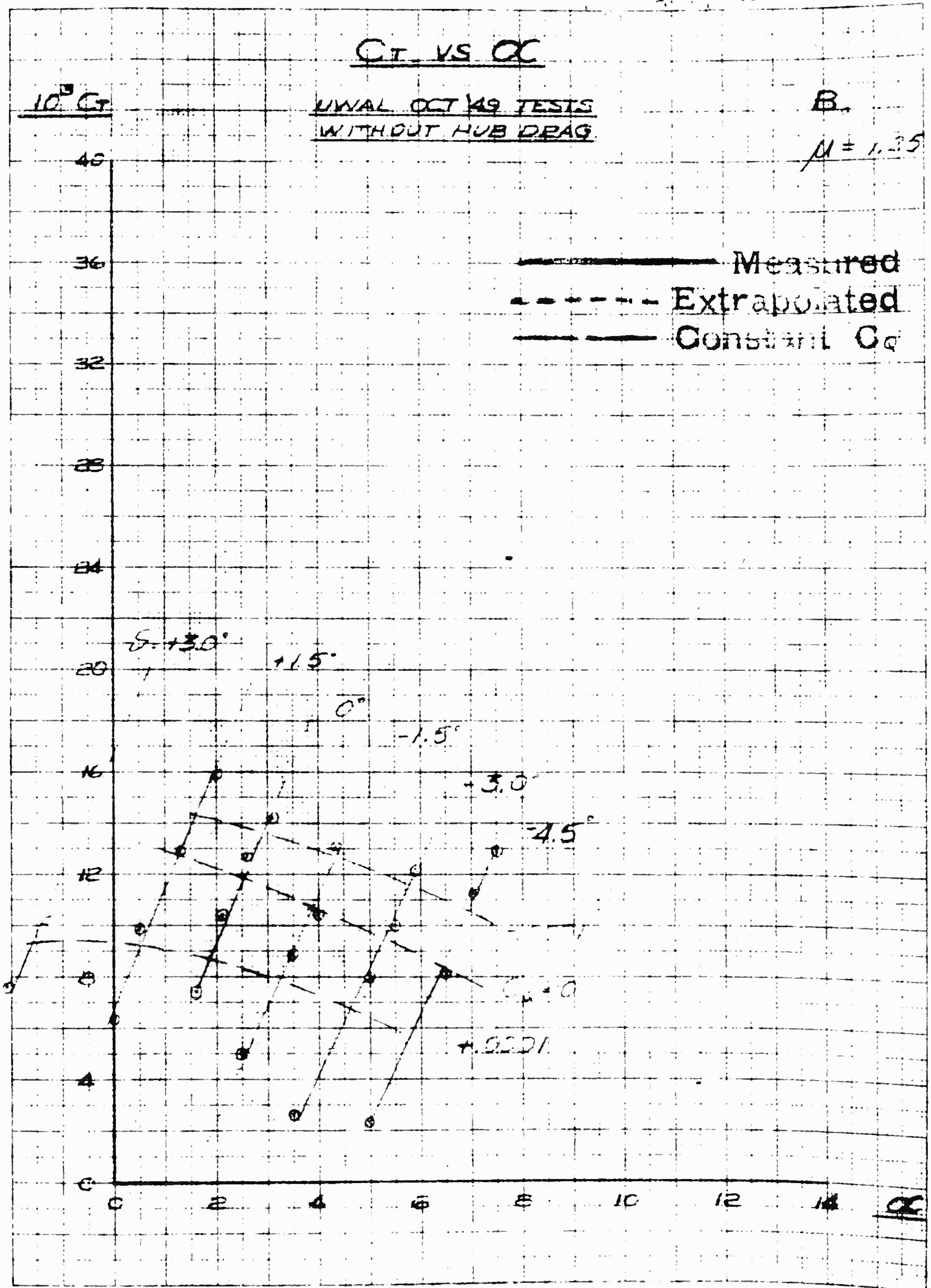


KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy

Page 50
Report 1973

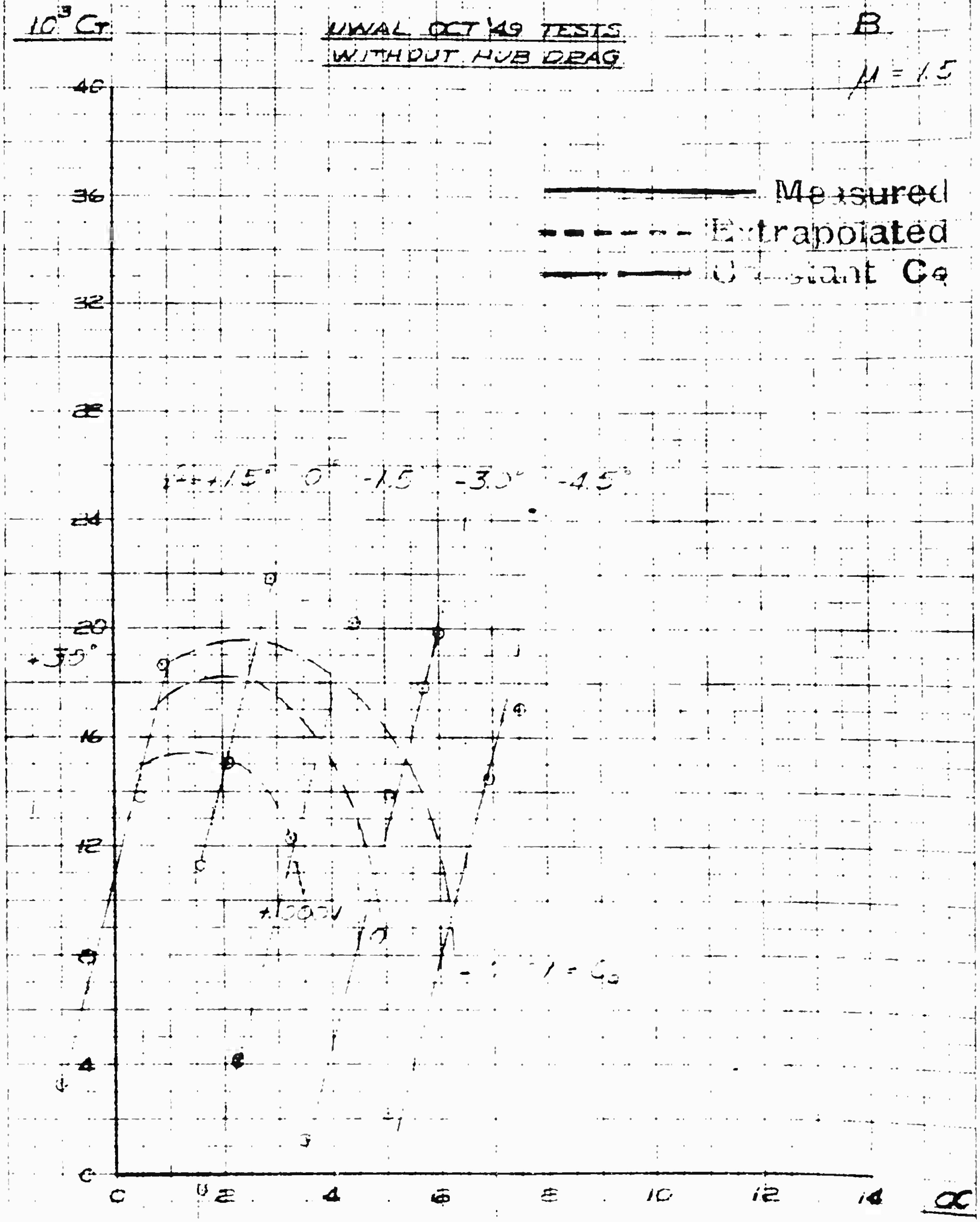


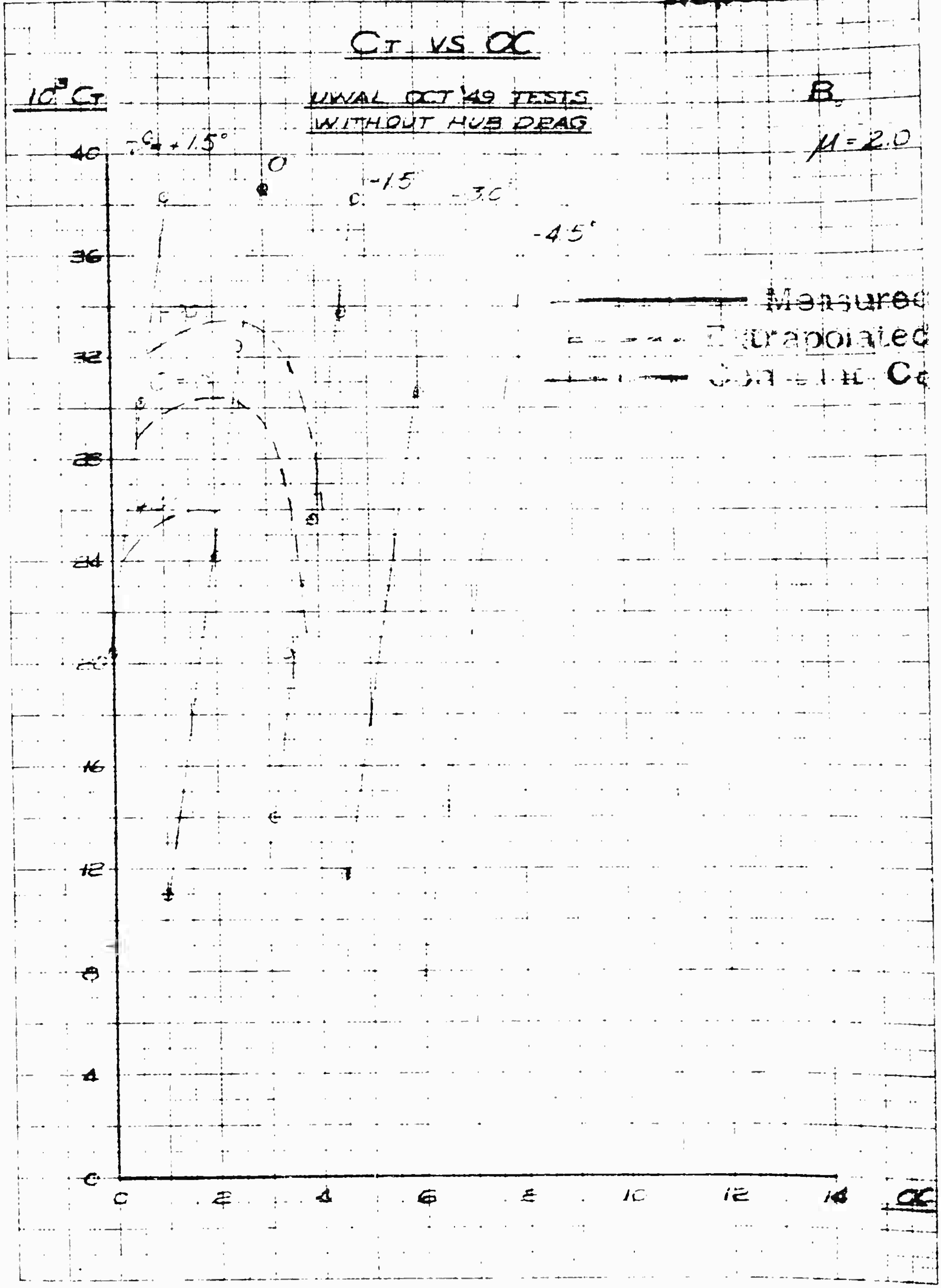
51

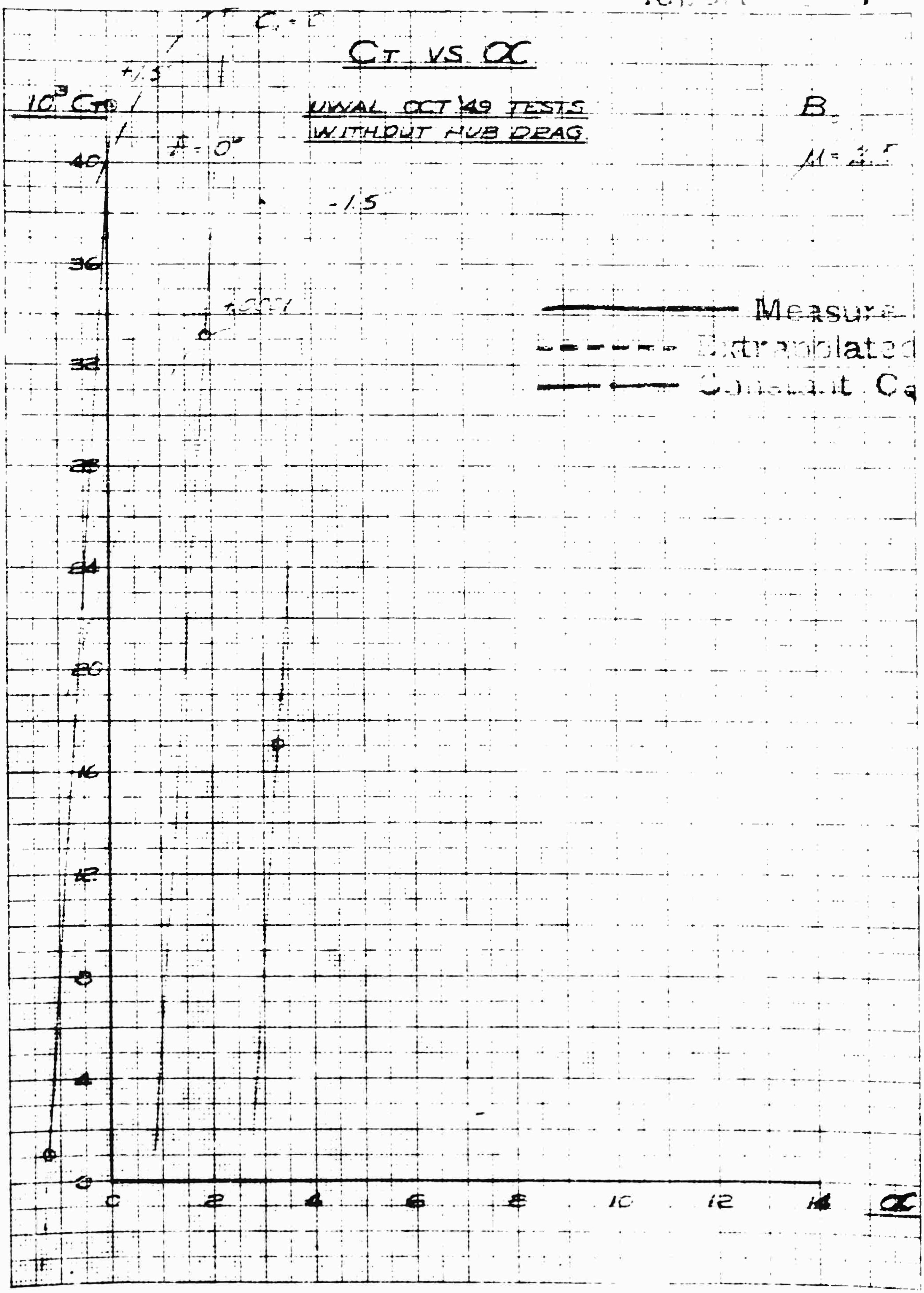


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

C_T vs α

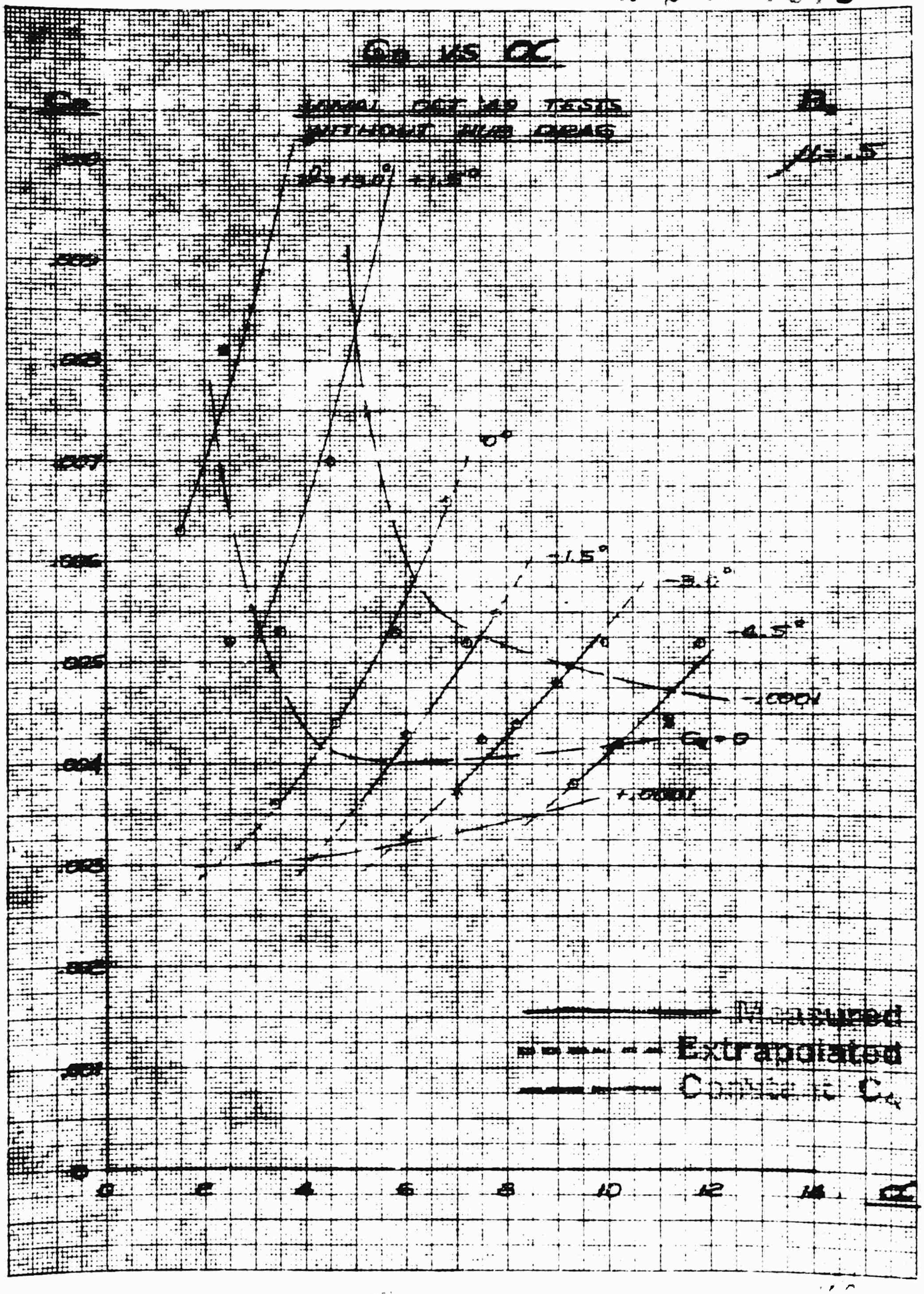

$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$\mu = 1.5$
Measured
Extrapolated
Constant C_Q
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
α


CT vs α
10³ CT
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
μ = 2.0
+15°
0
-15
-30
-45°
Measured
Extrapolated
40
36
32
28
24
20
16
12
8
4
0
2
4
6
8
10
12
14
α

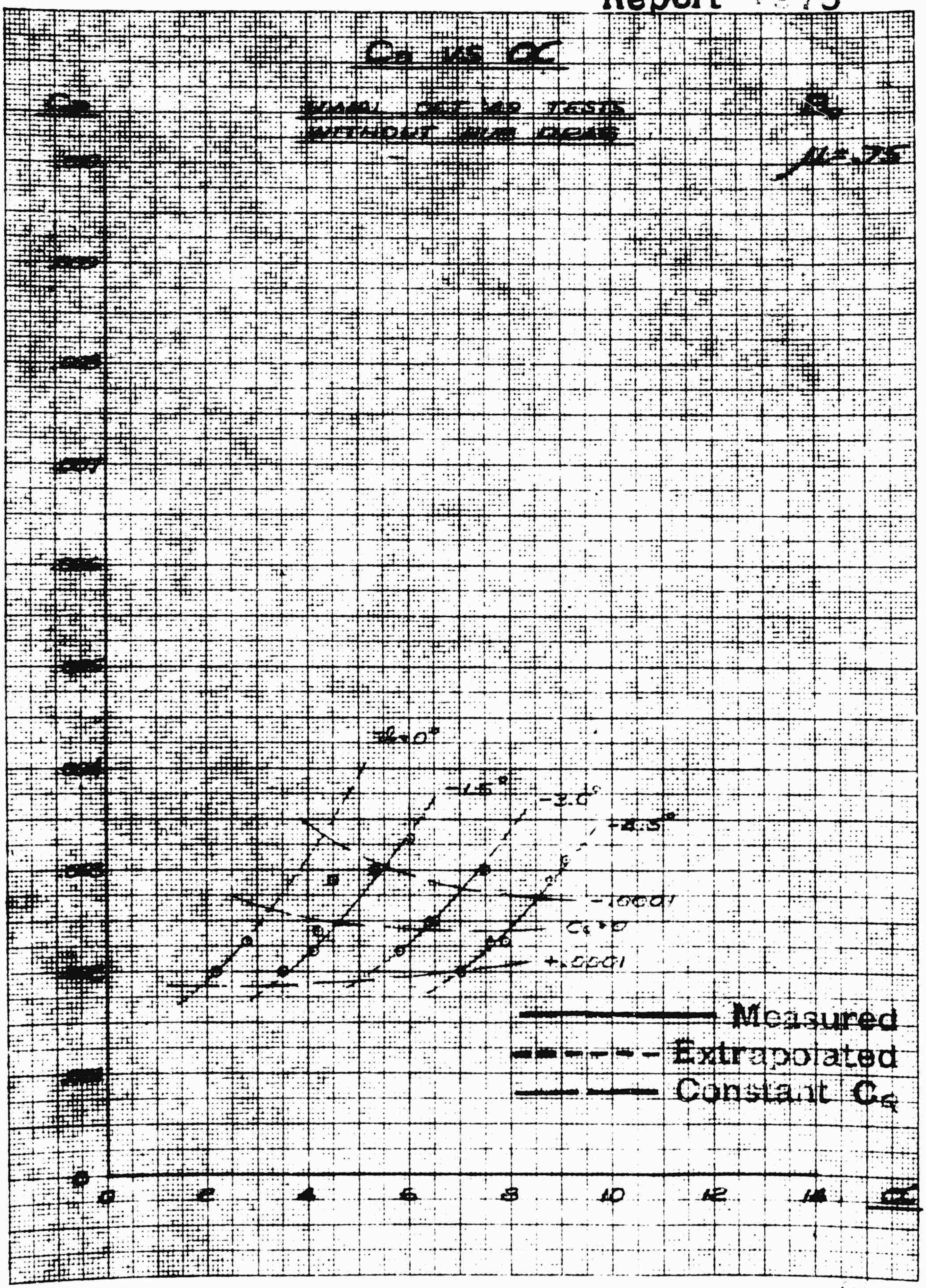


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

55

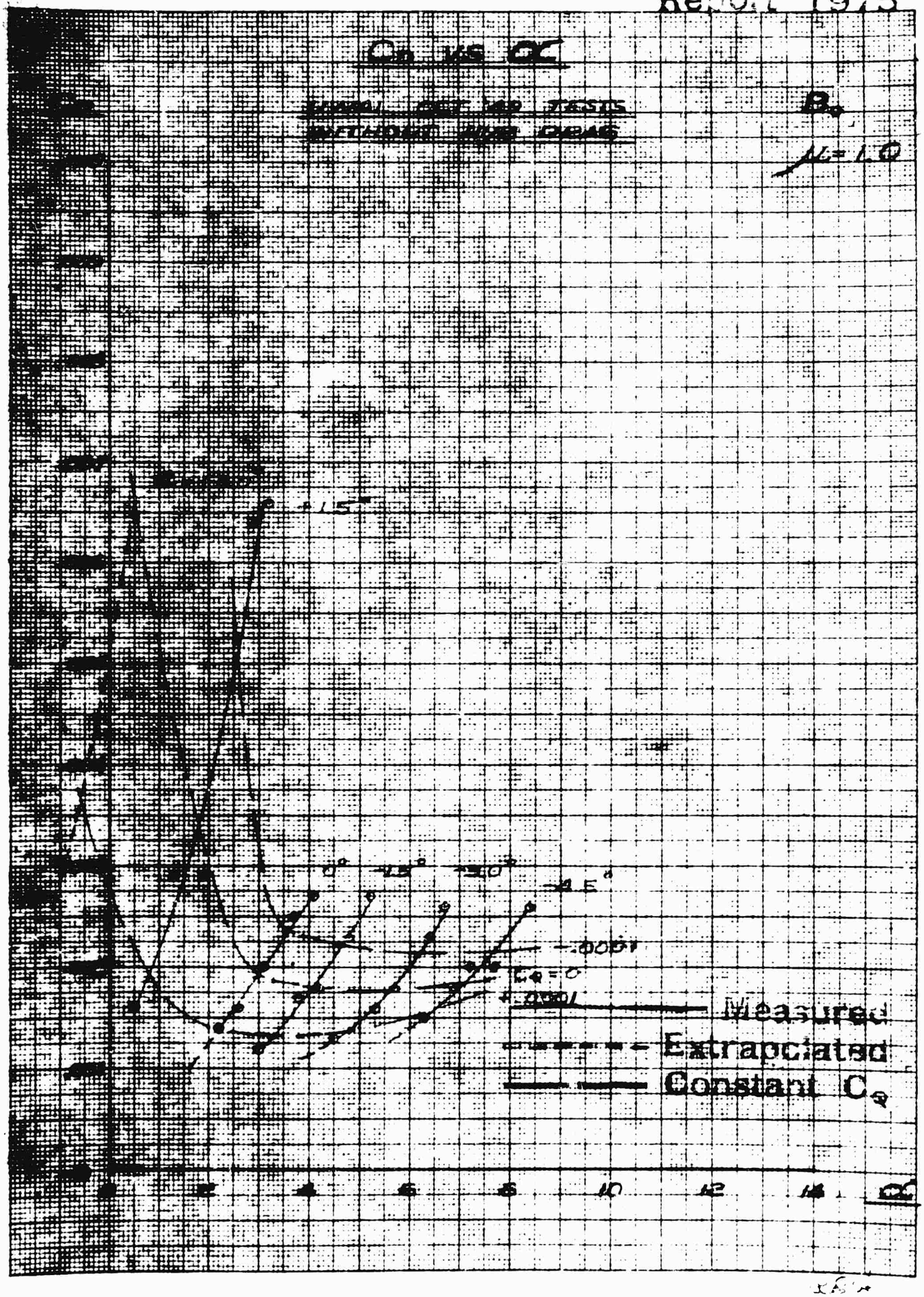


No 359 14. Millimeters, 5 mm lines accented, cm lines heavy.
KEUFFEL & ESSER CO.

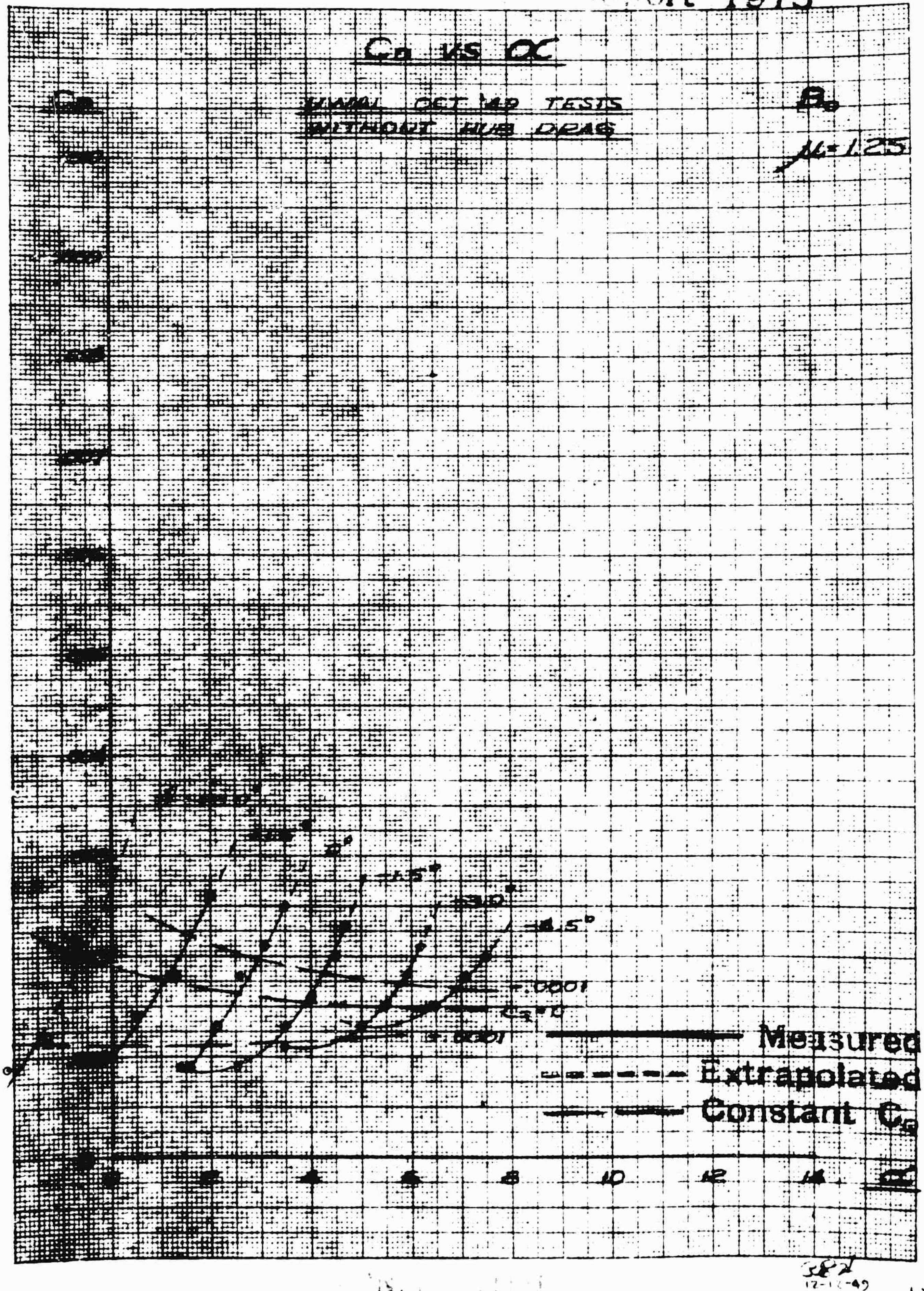


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

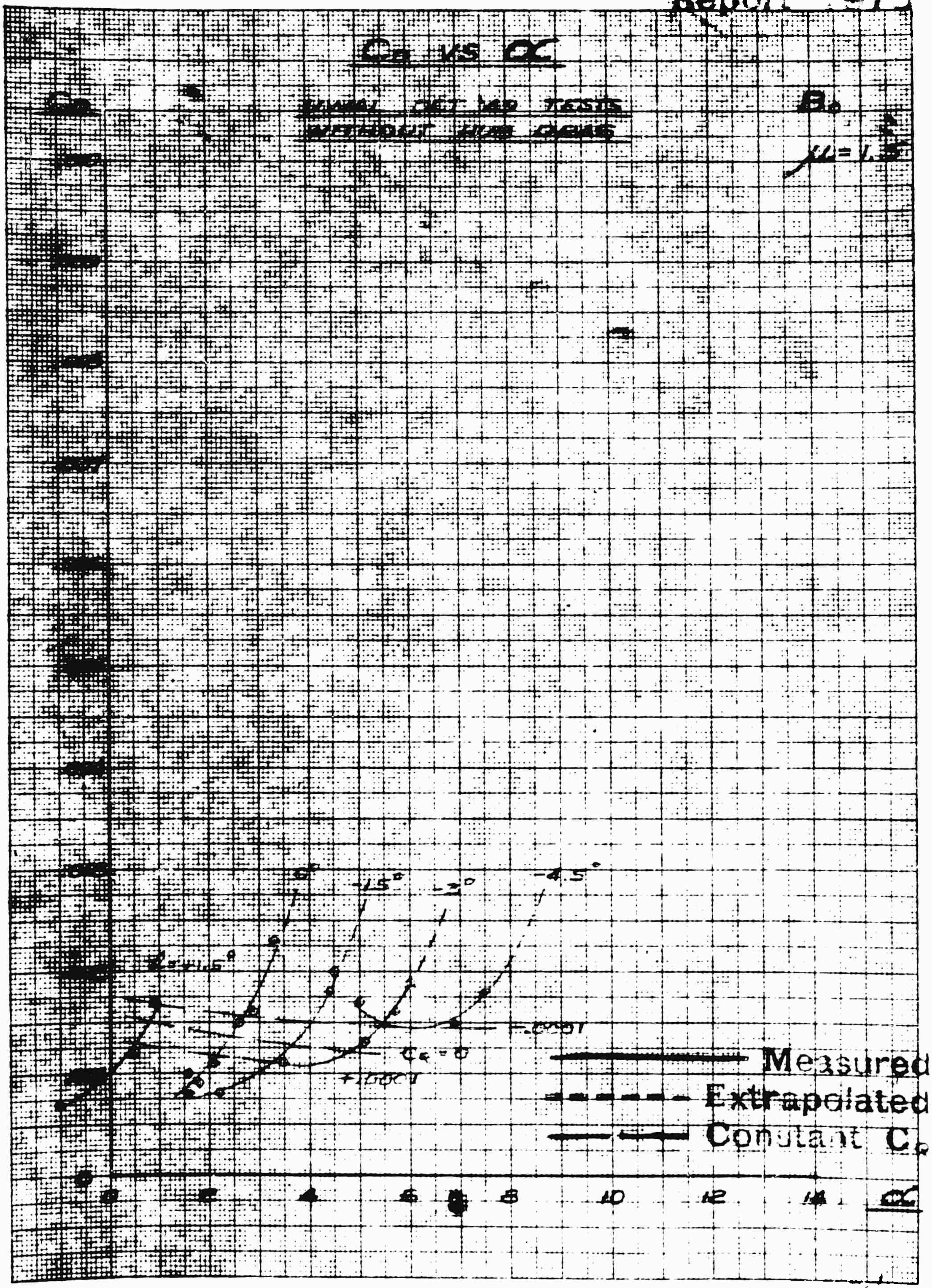


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



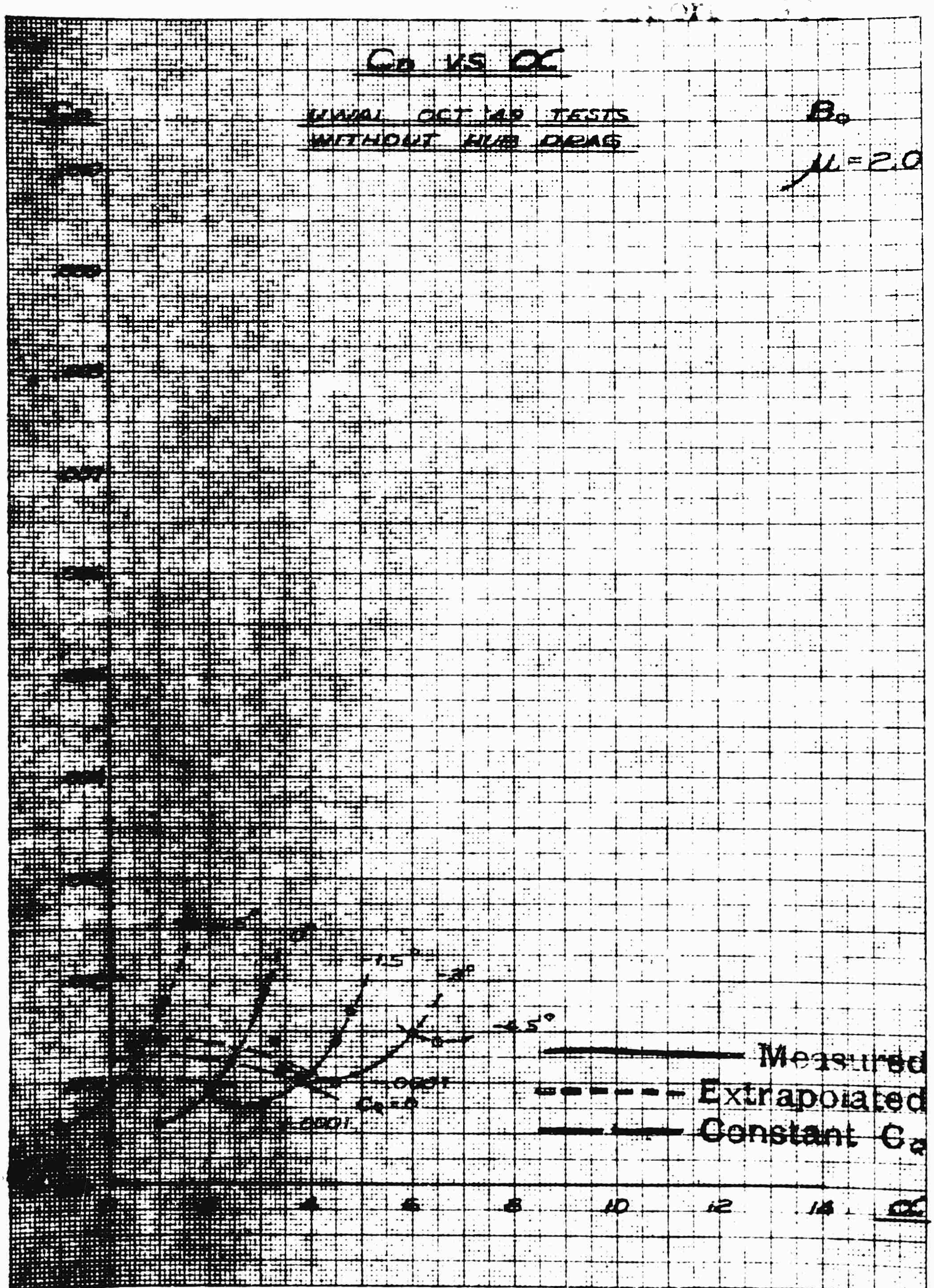
KEUFFEL & ESSER CO.
No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.

582
12-12-49

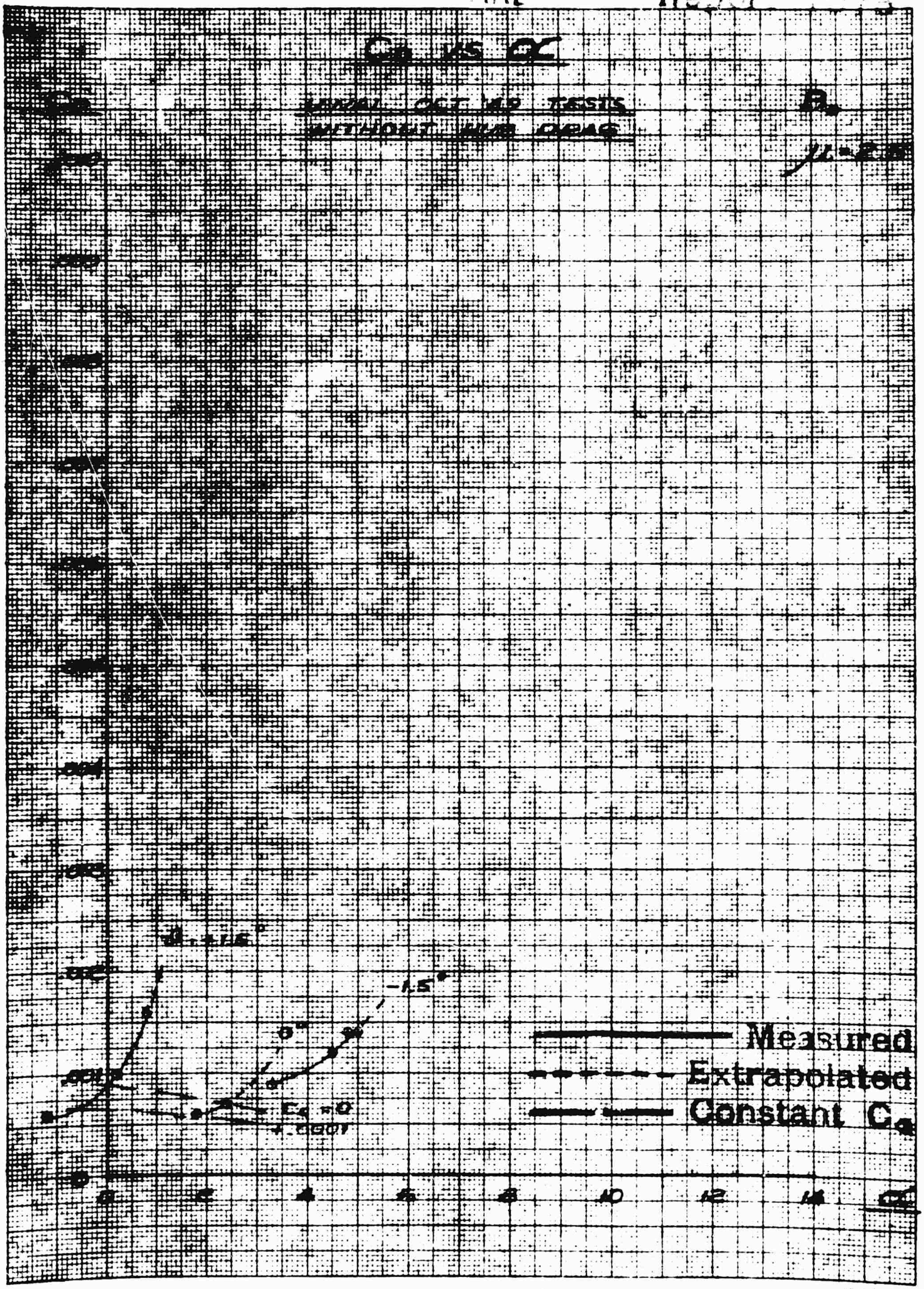


KEUFFEL & ESSER CO.

No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy.

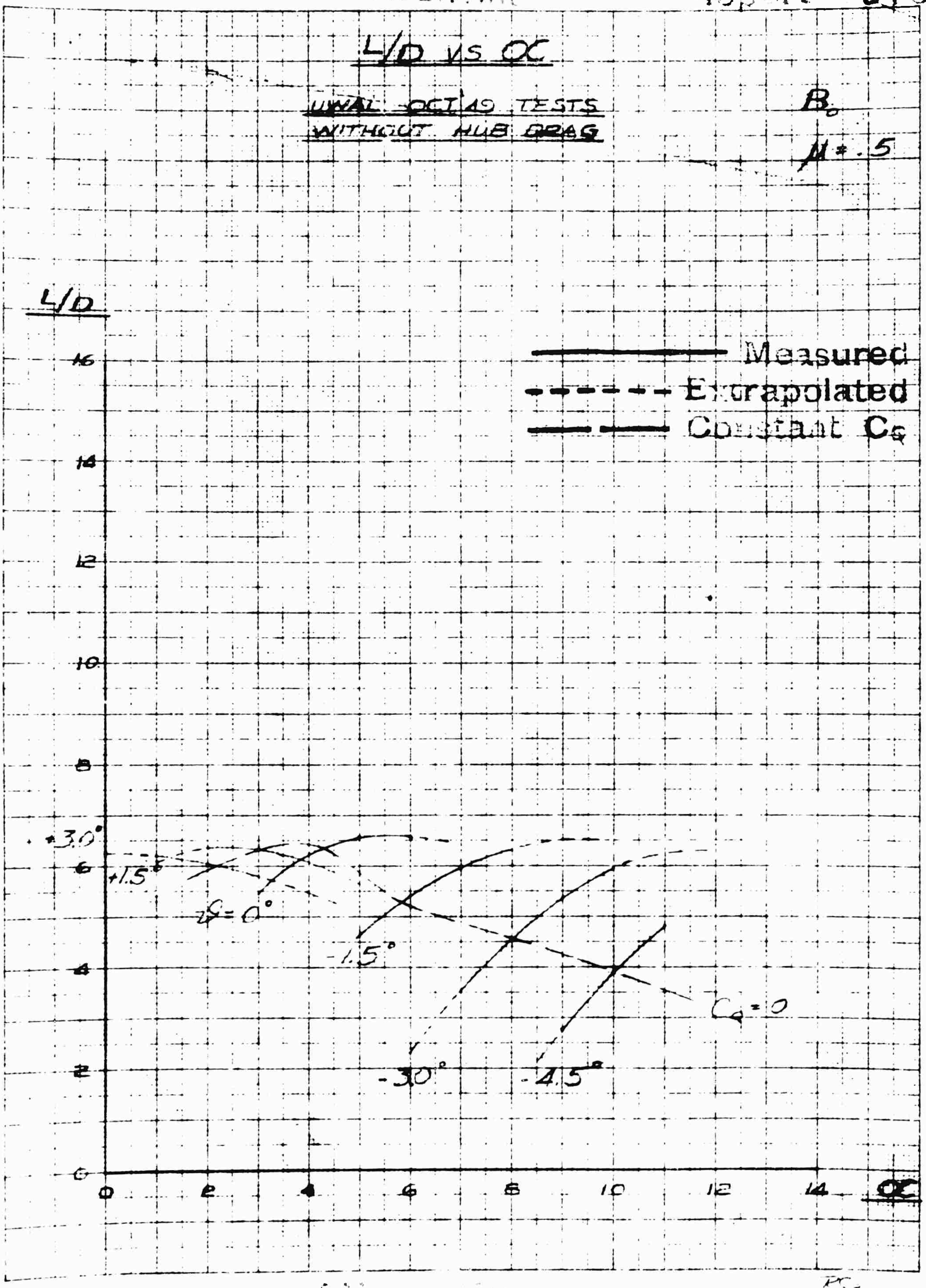


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.



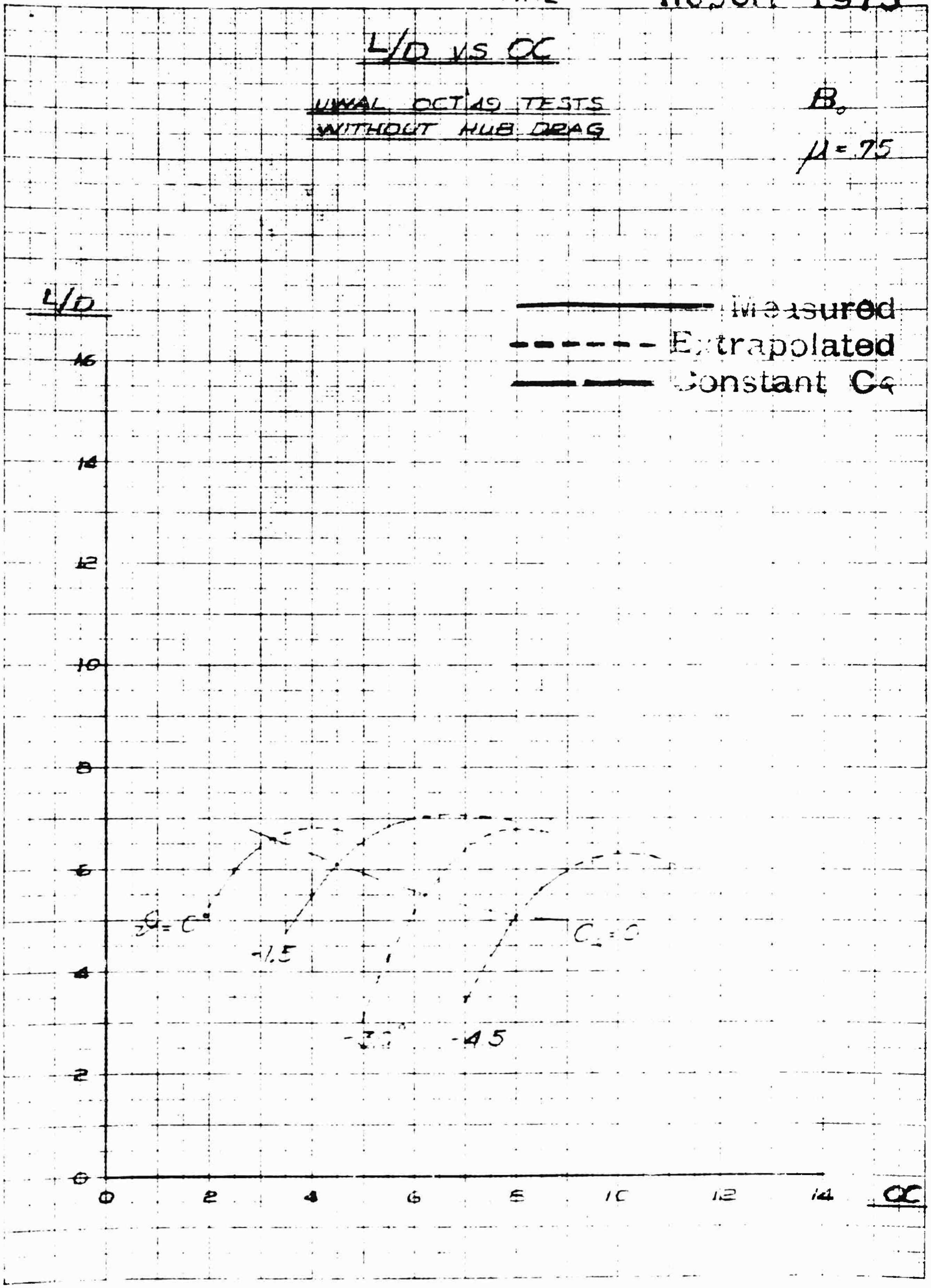
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

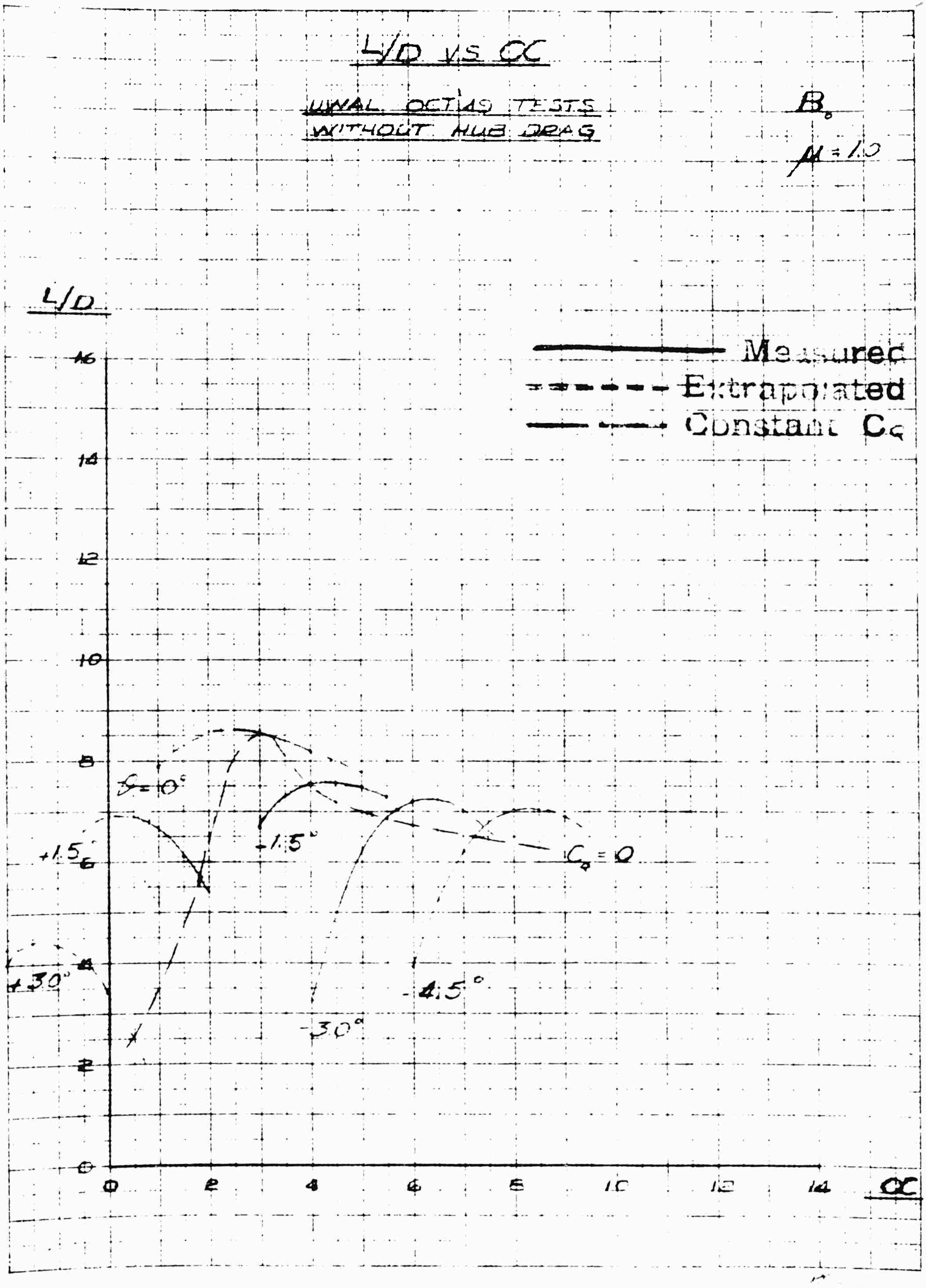


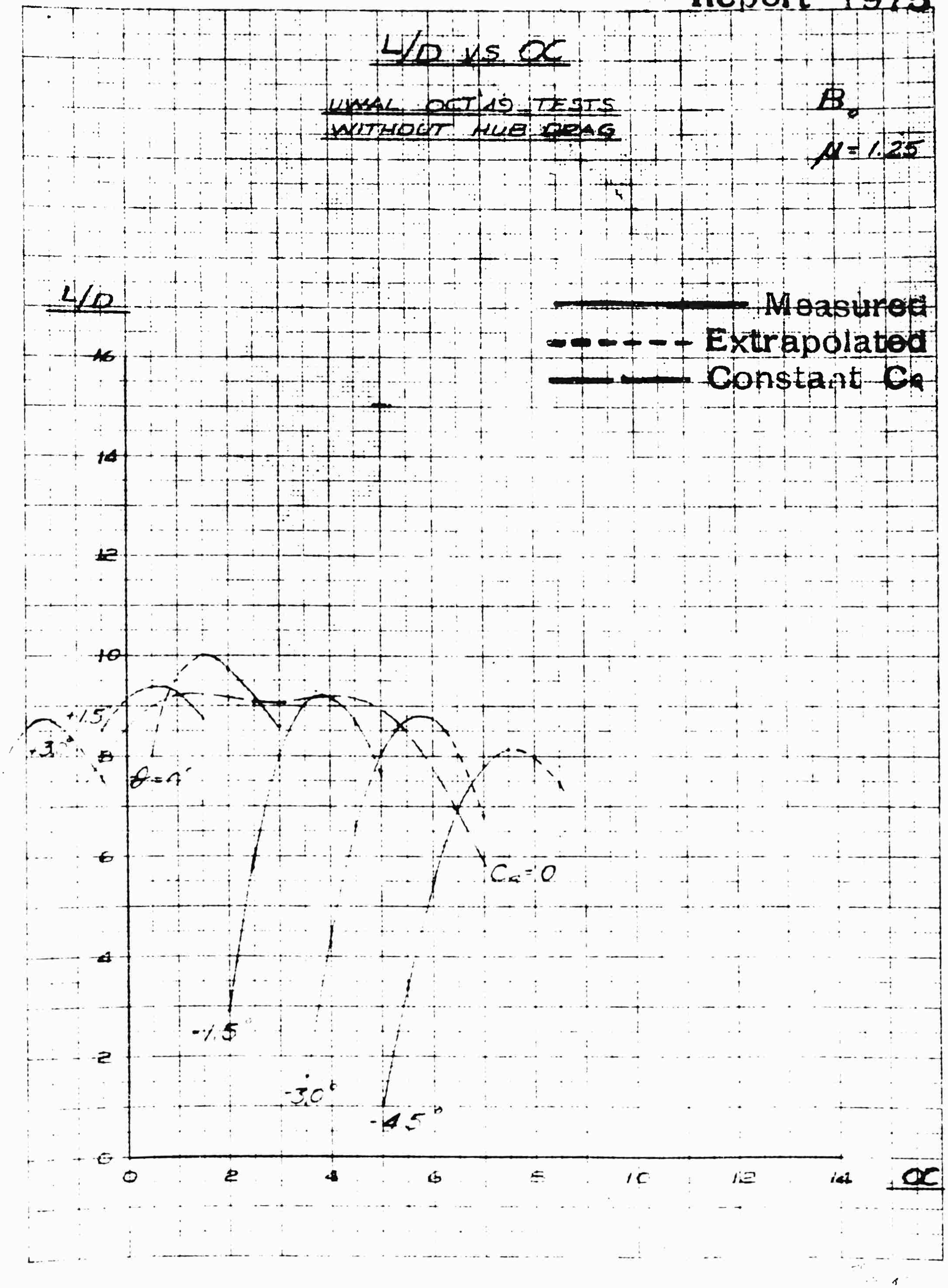
CONFIDENTIAL

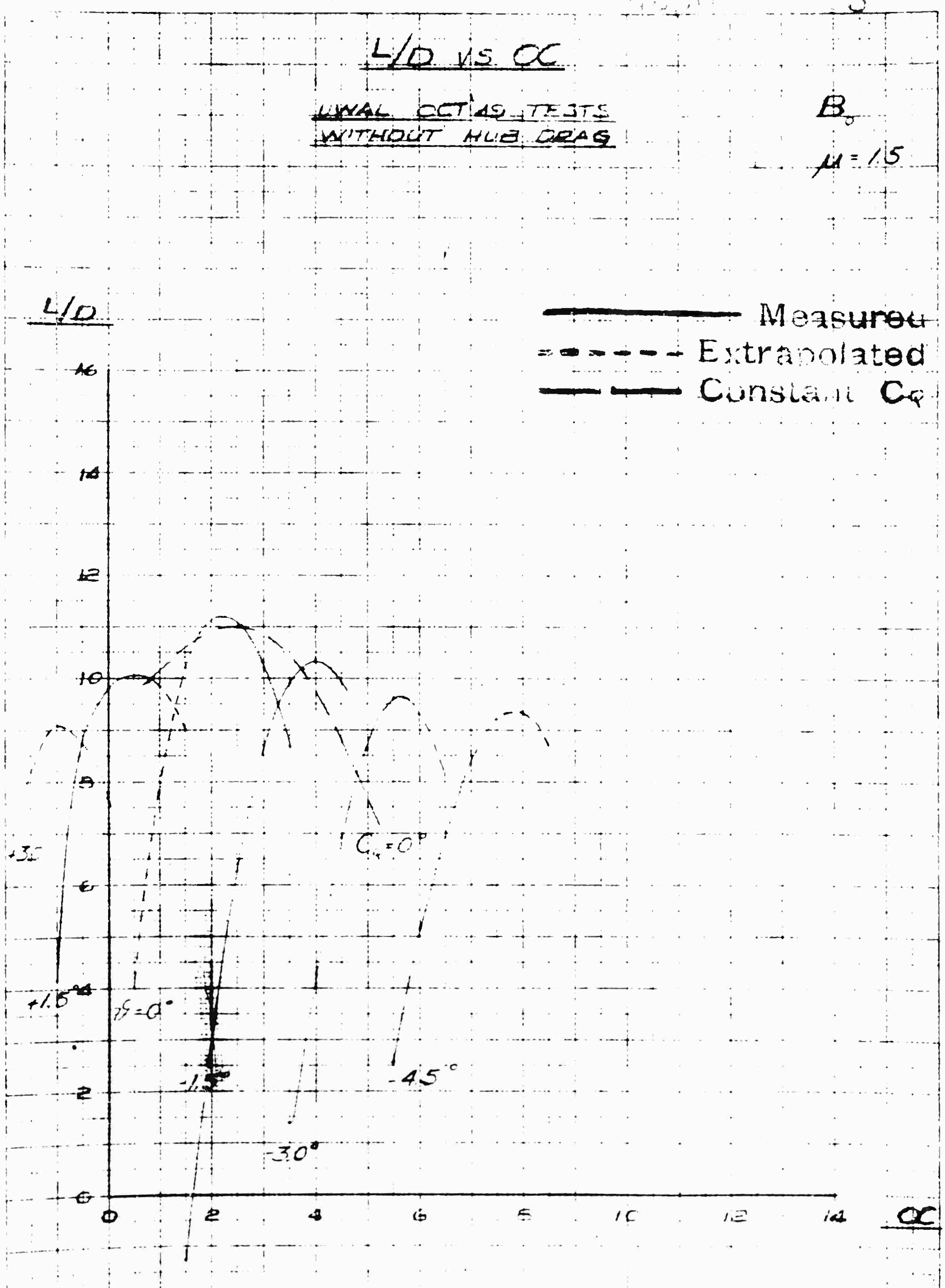
CONFIDENTIAL

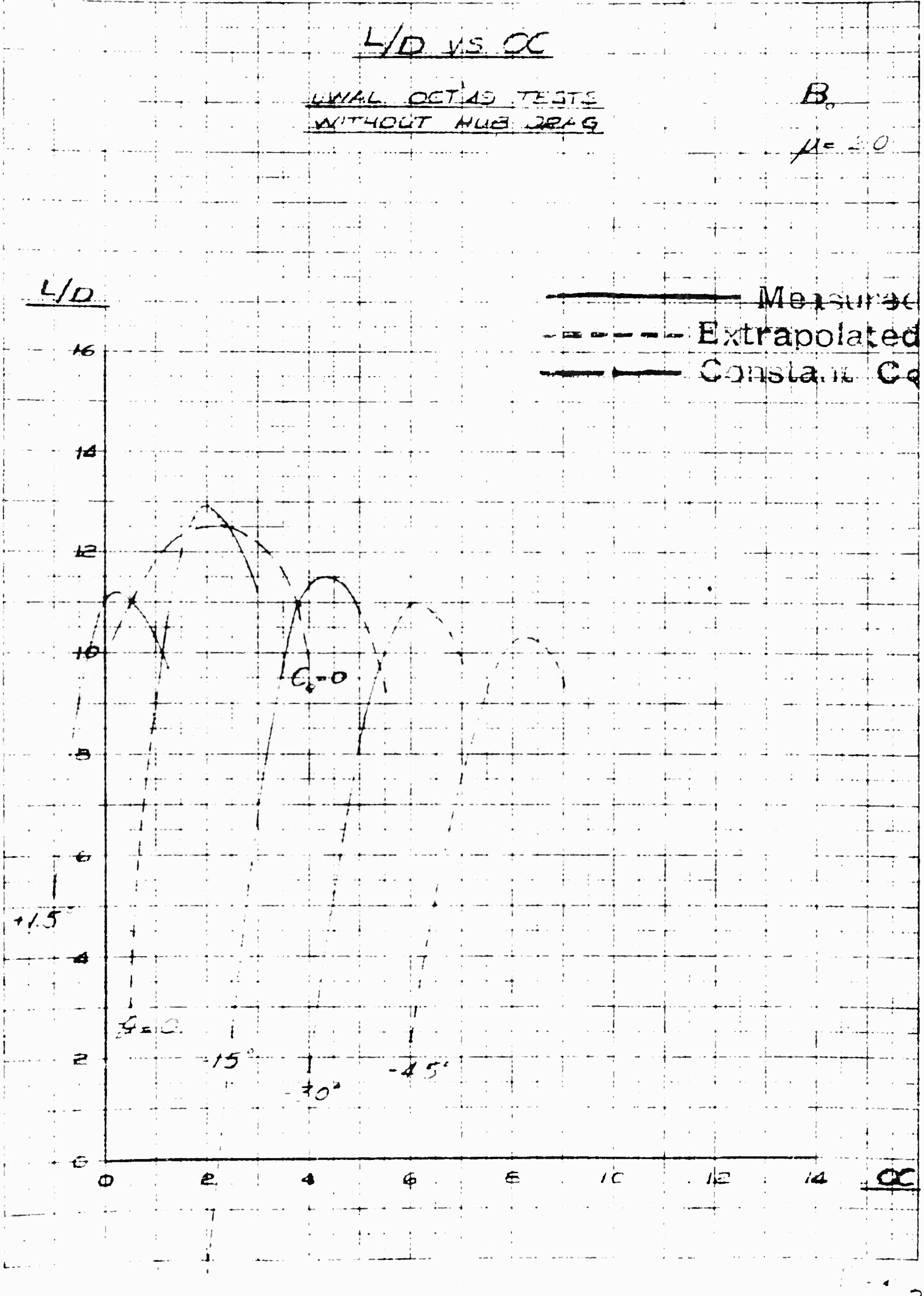


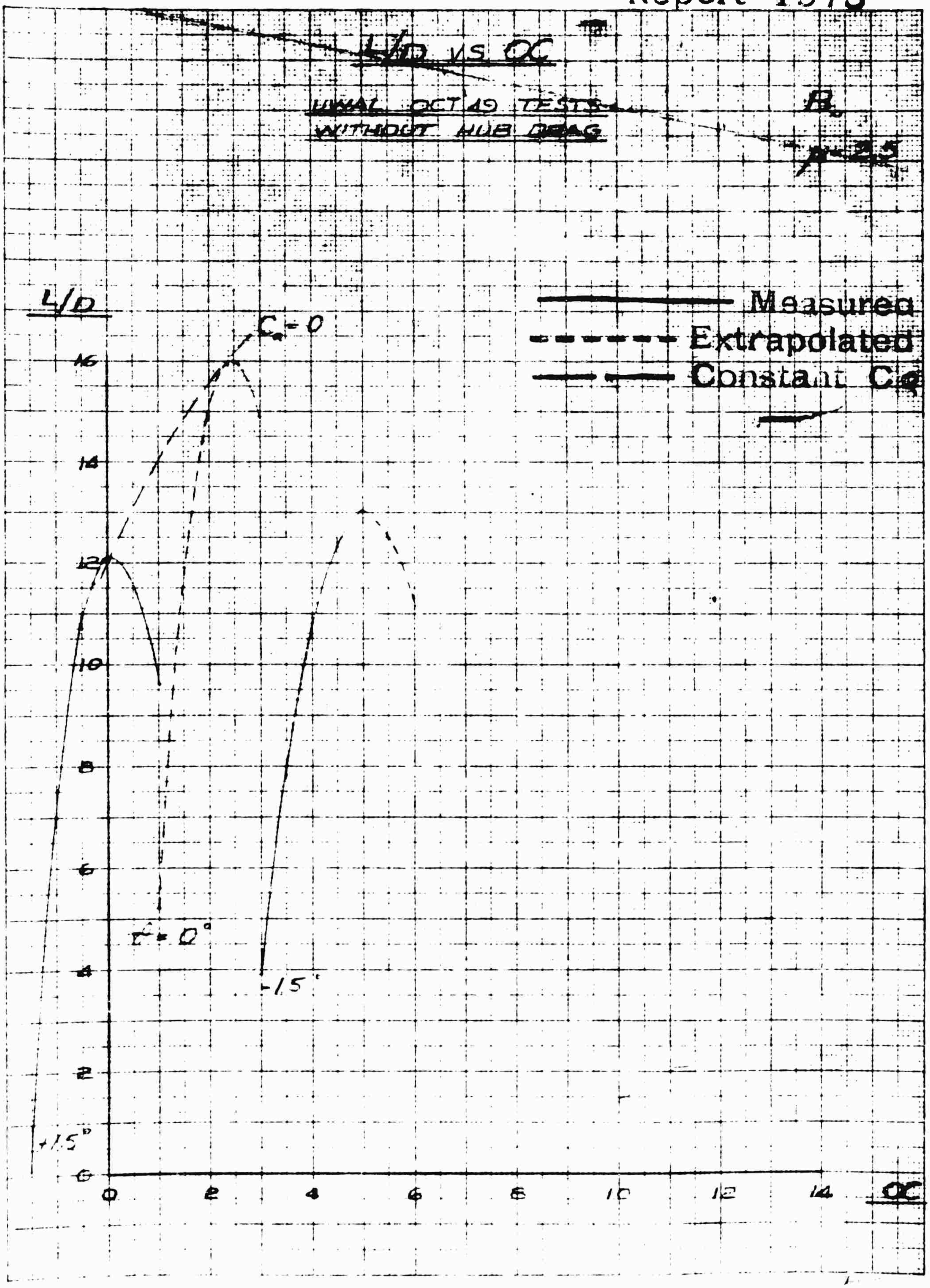
CONFIDENTIAL



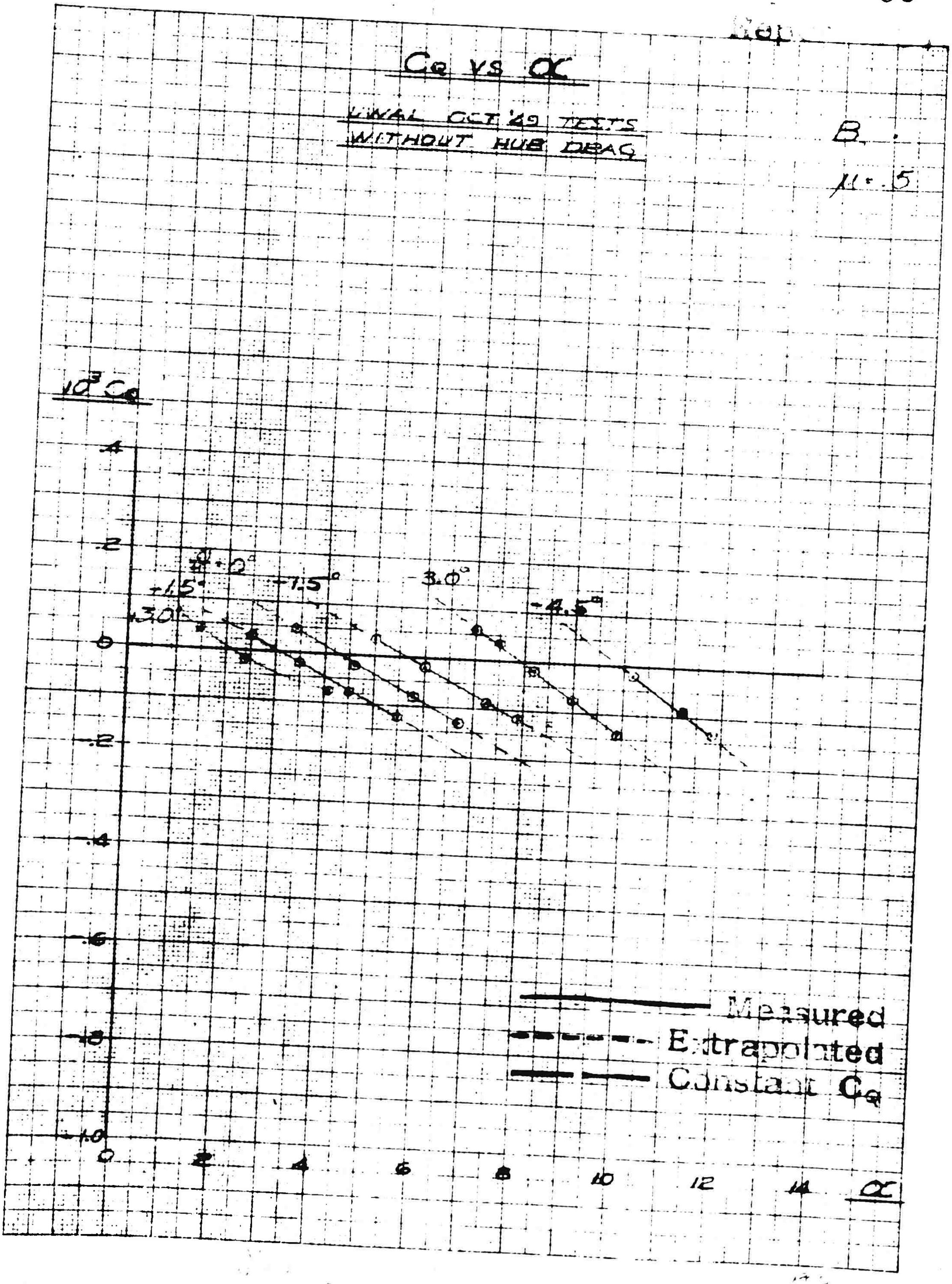

L/D vs OC
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
μ = 1.25
L/D
Measured
Extrapolated
Constant C
16
14
12
10
8
6
4
2
0
+1.5
+3°
θ = 0°
C = 0
-1.5
-3.0°
-4.5°
0
2
4
6
8
10
12
14
OC


L/D VS OC
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
μ = .15
L/D
Measured
Extrapolated
Constant Cq
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
+1.5°
+3.5°
Cq = 0°
-1.5°
-3.0°
-4.5°


L/D vs. α
UWAL OCT '45 TESTS
WITHOUT HUB DRAG
B₀
μ = .30
L/D
Measured
Extrapolated
Constant Cq
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
Cq = 0
+1.5°
θ = 0
-15°
-30°
-45°



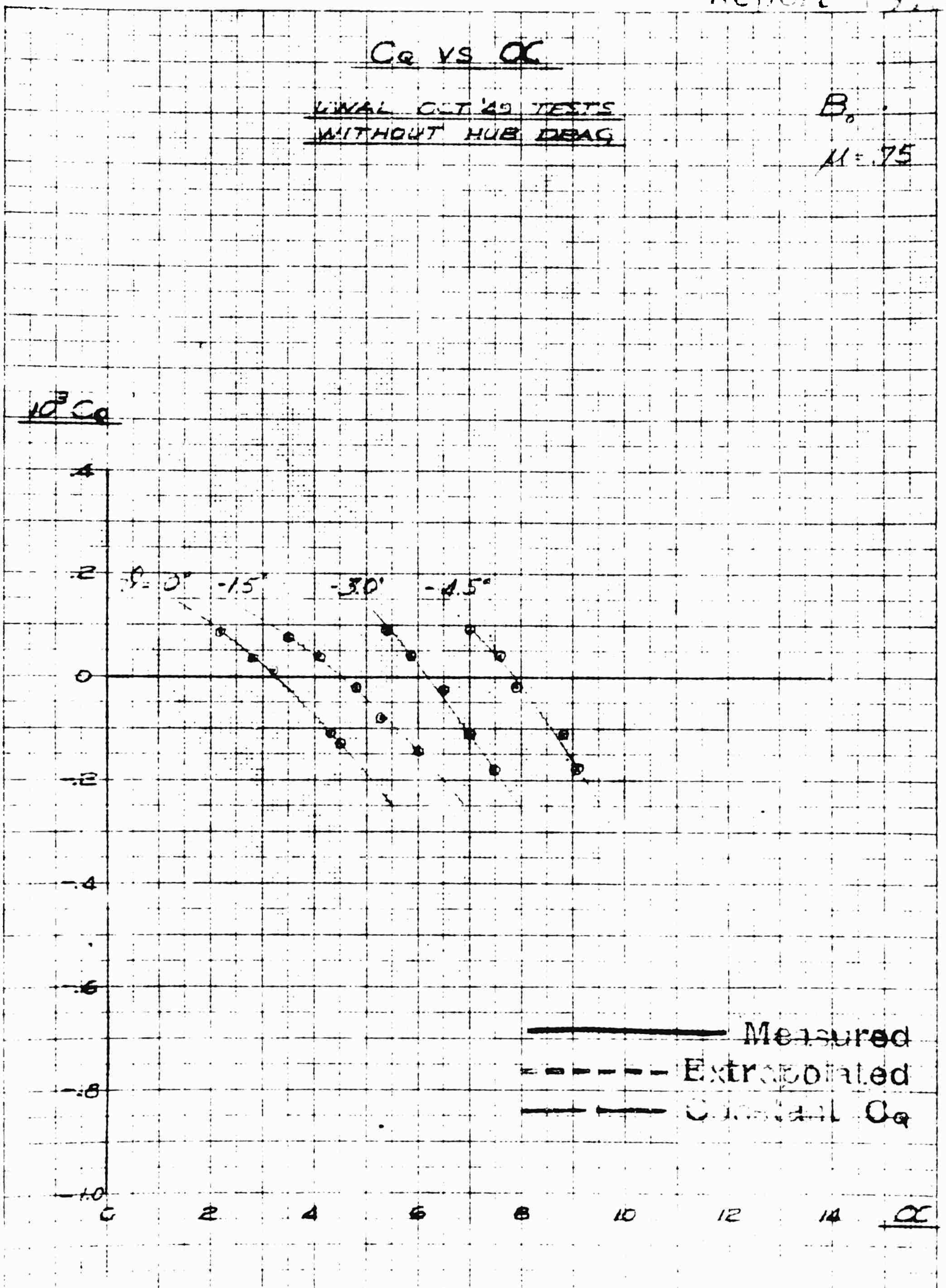
KEUFFEL & ESSER CO.



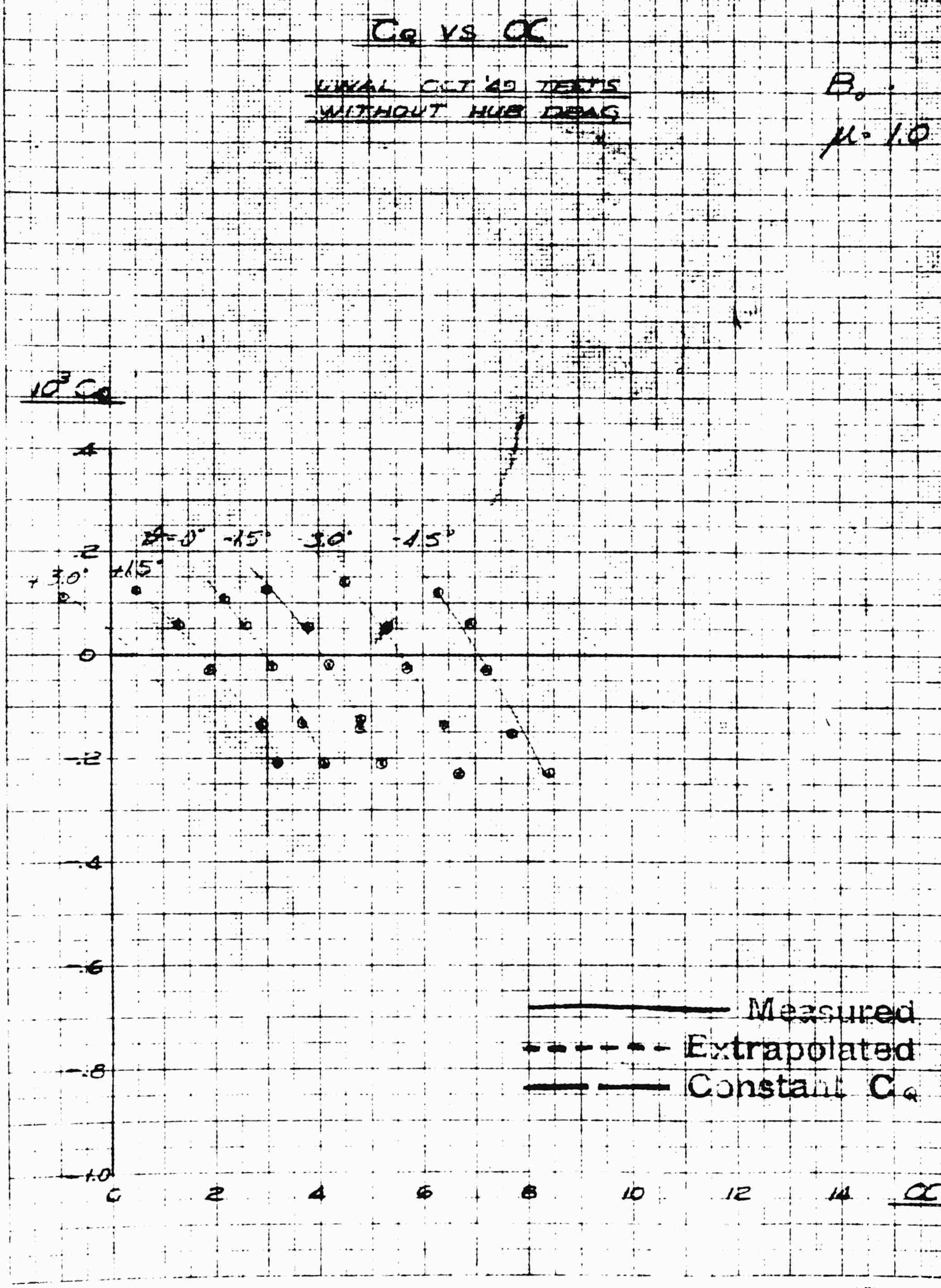
Millimeters, 5 mm lines accented, cm lines heavy

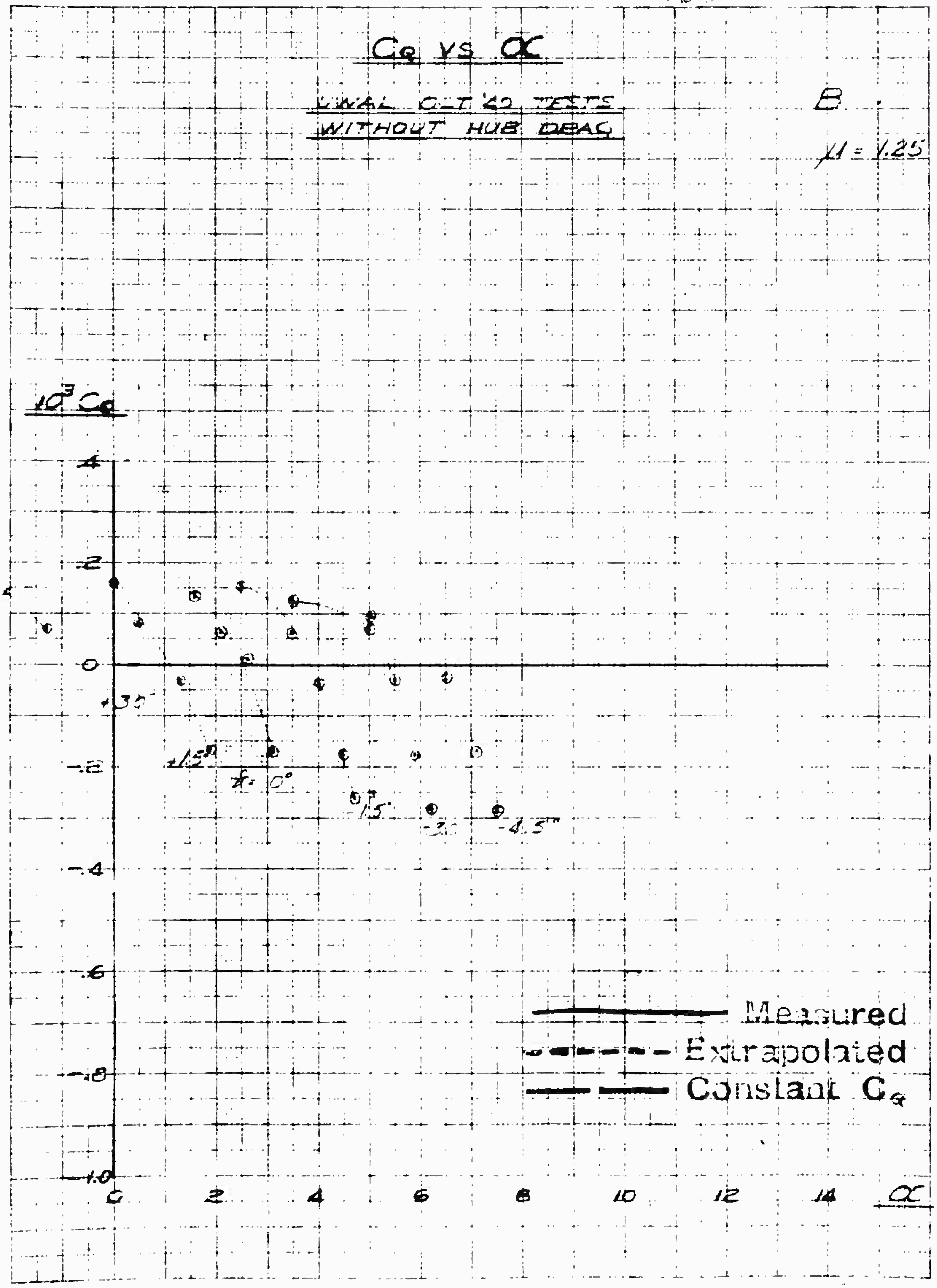
KEUFFEL & ESSER CO.

No. 359-14

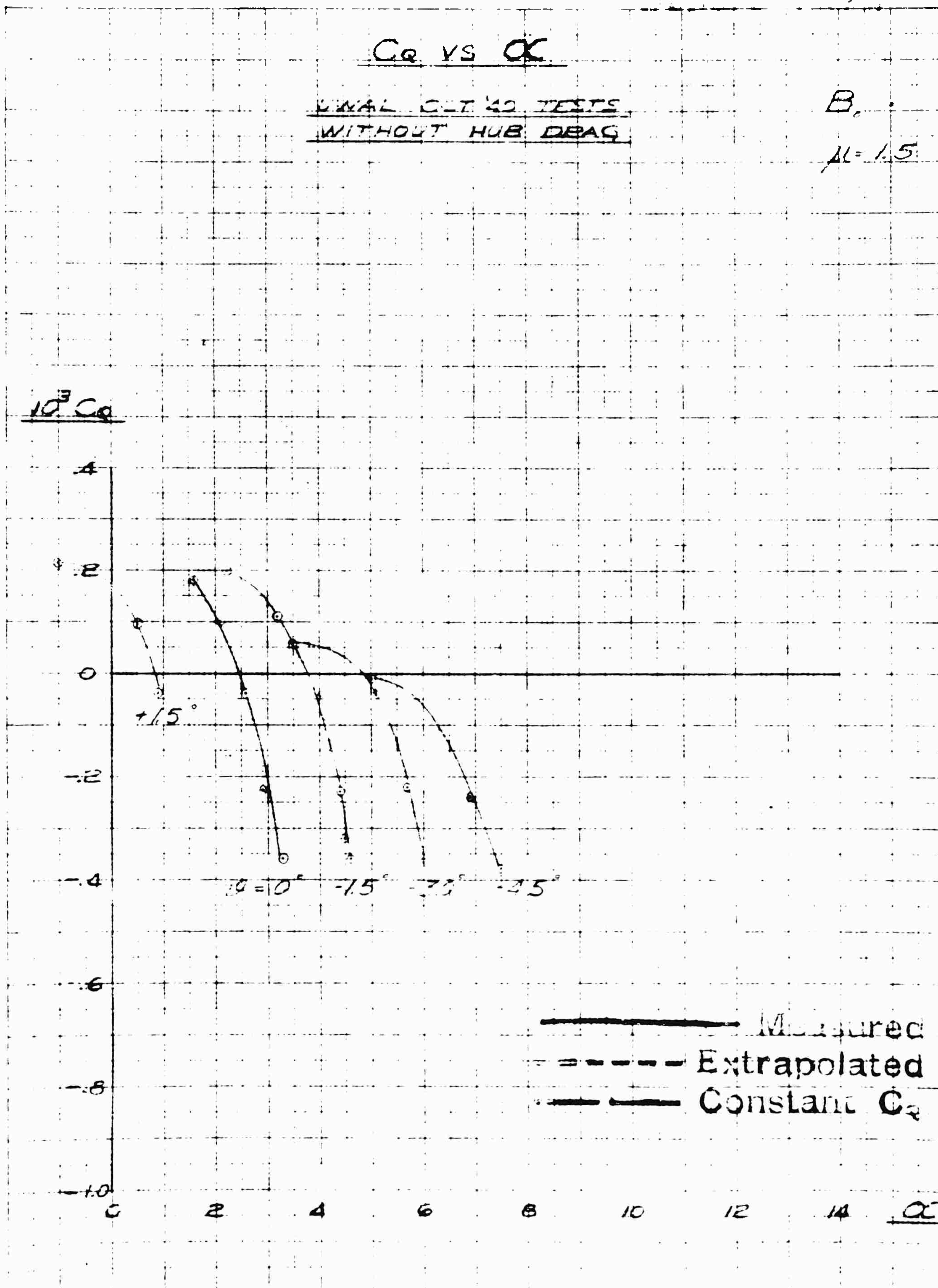


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

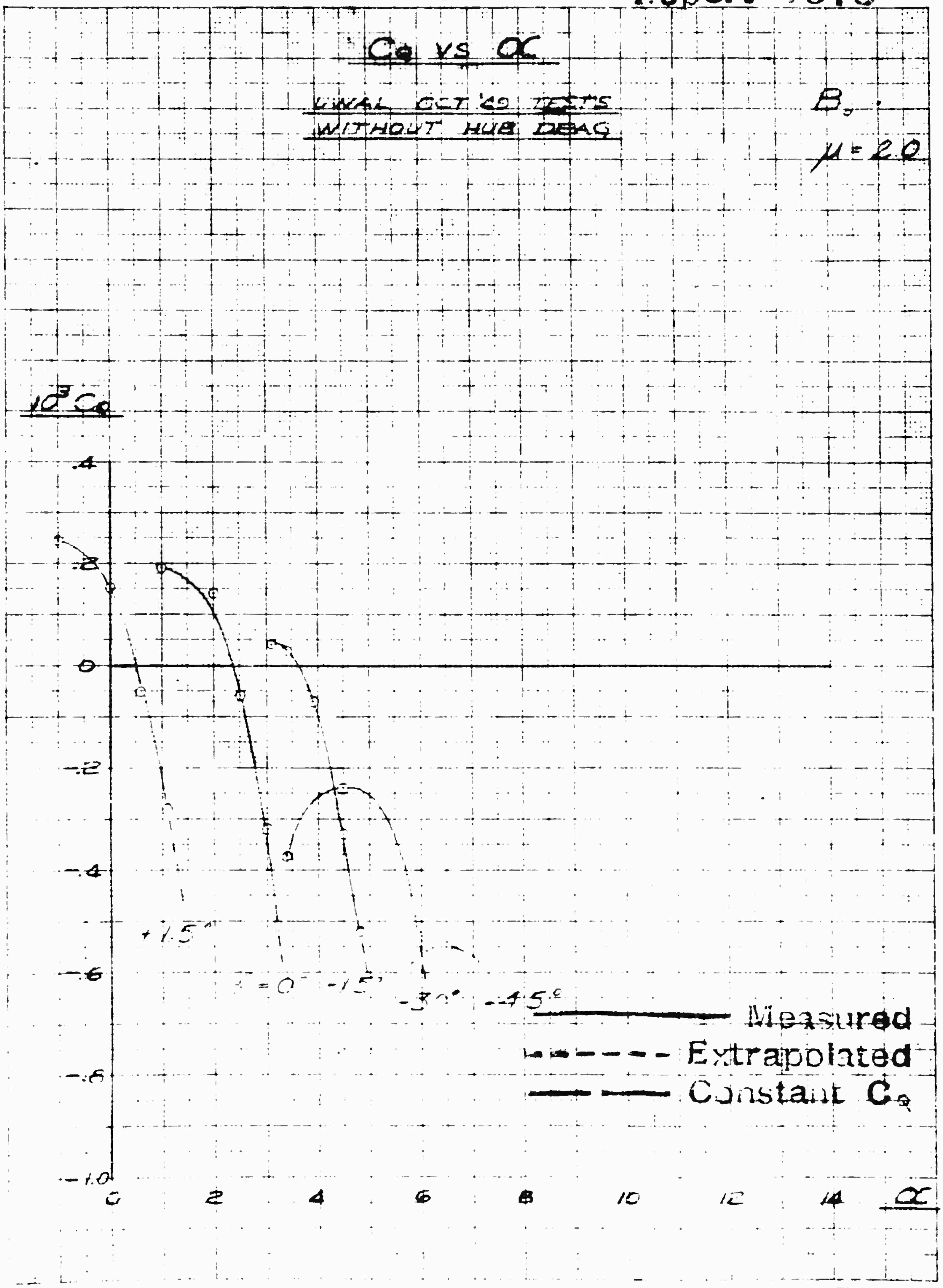

$\overline{C_Q}$ VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
μ = 1.0
$10^3 C_Q$
-3.0° -1.5° -3.0° -4.5°
+3.0° +1.5°
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0 2 4 6 8 10 12 14
α
Measured
Extrapolated
Constant C_Q

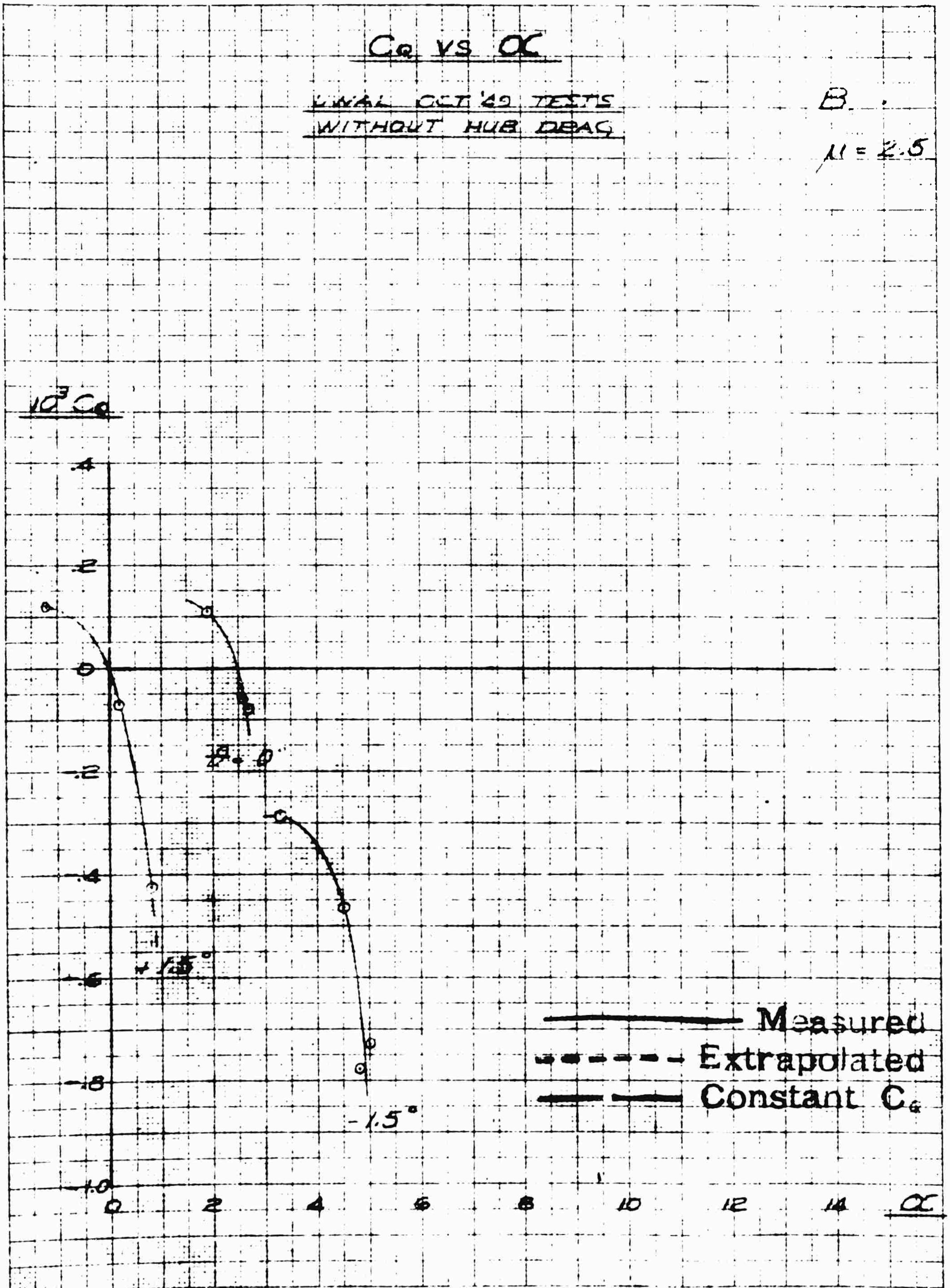


C_Q VS α
UWAL OCT '42 TESTS
WITHOUT HUB DRAG
B
$\mu = 1.25$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
+3.5°
+1.5°
θ = 0°
-1.5°
-3.0
-4.5°
Measured
Extrapolated
Constant C_Q

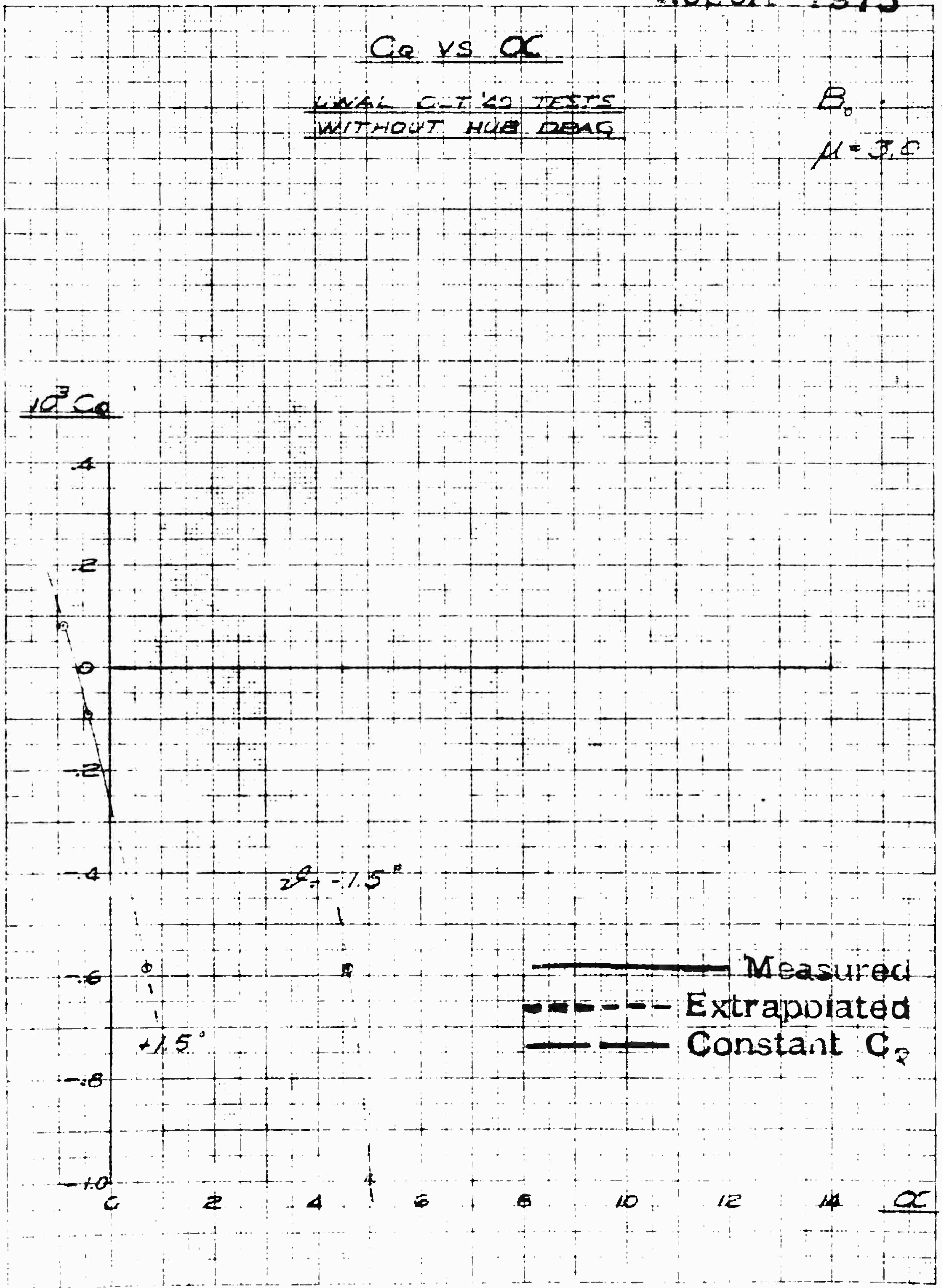


CQ VS α
FINAL CLT '42 TESTS
WITHOUT HUB DRAG
μ = 1.5
10³ CQ
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
+1.5°
θ = 0°
-1.5°
-2.5°
0
2
4
6
8
10
12
14
α
Extrapolated
Constant CQ

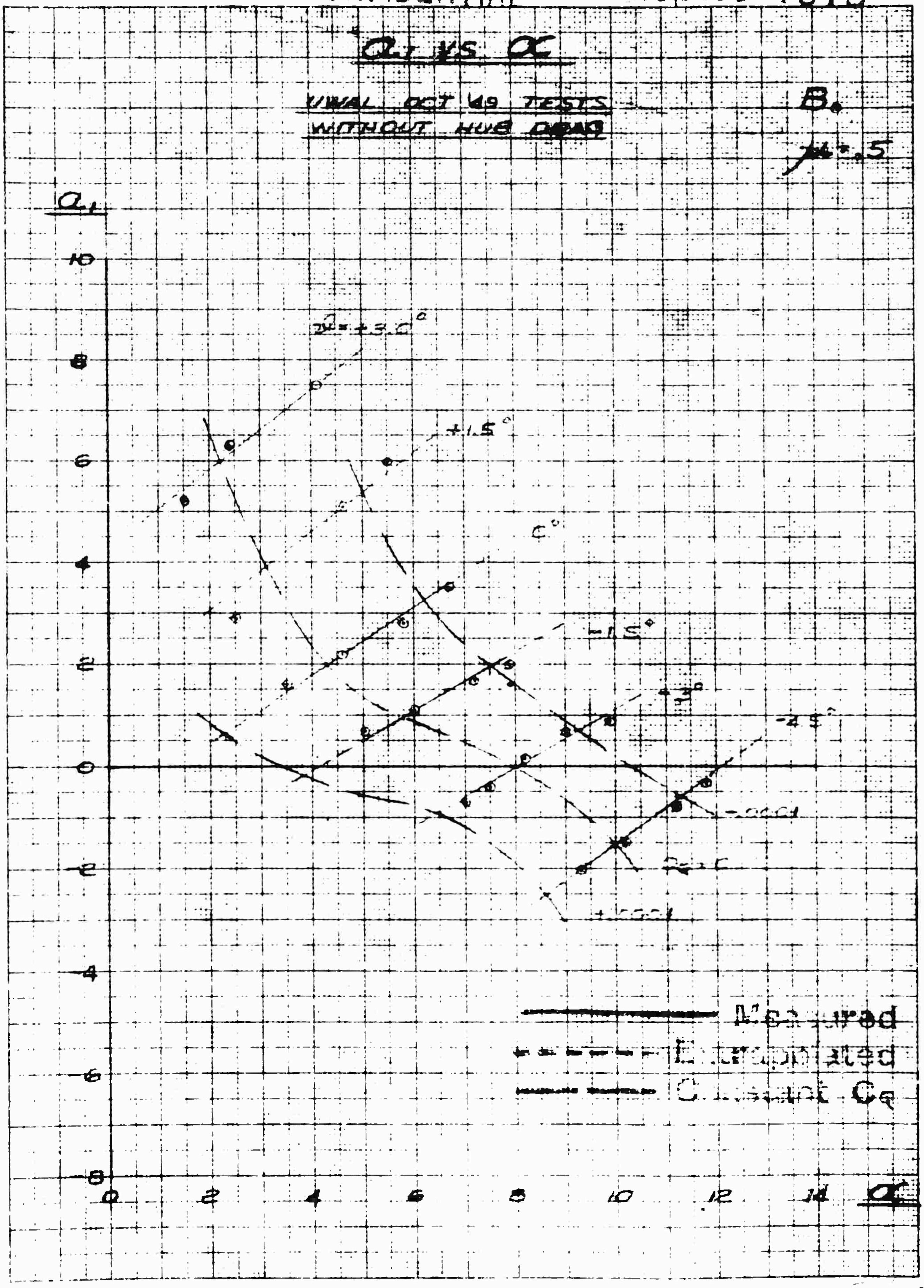

C_Q vs α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_2
$\mu = 2.0$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
+1.5°
= 0°
-1.5°
-3.0°
-4.5°
Measured
Extrapolated
Constant C_T

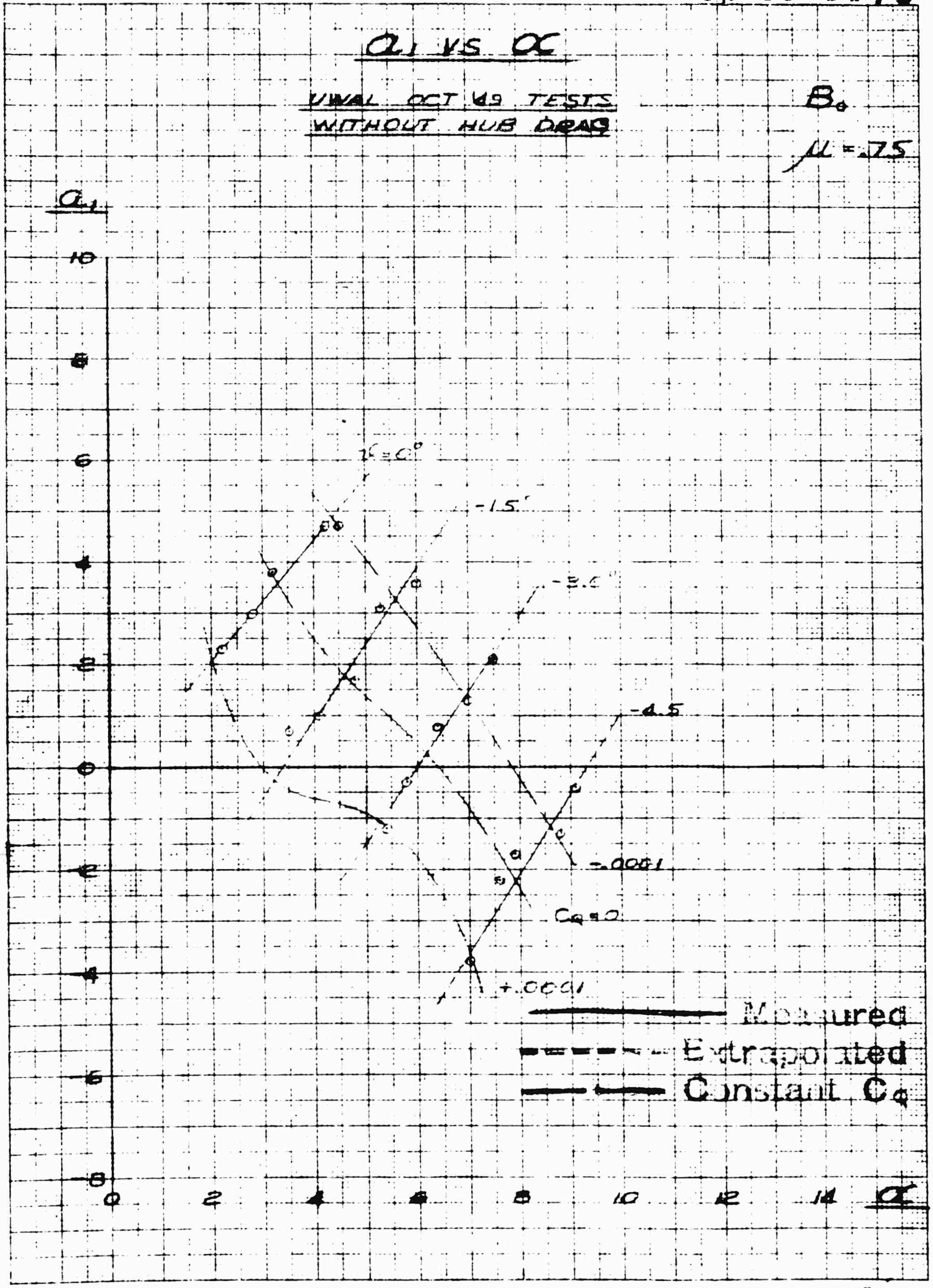


KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented cm lines heavy.

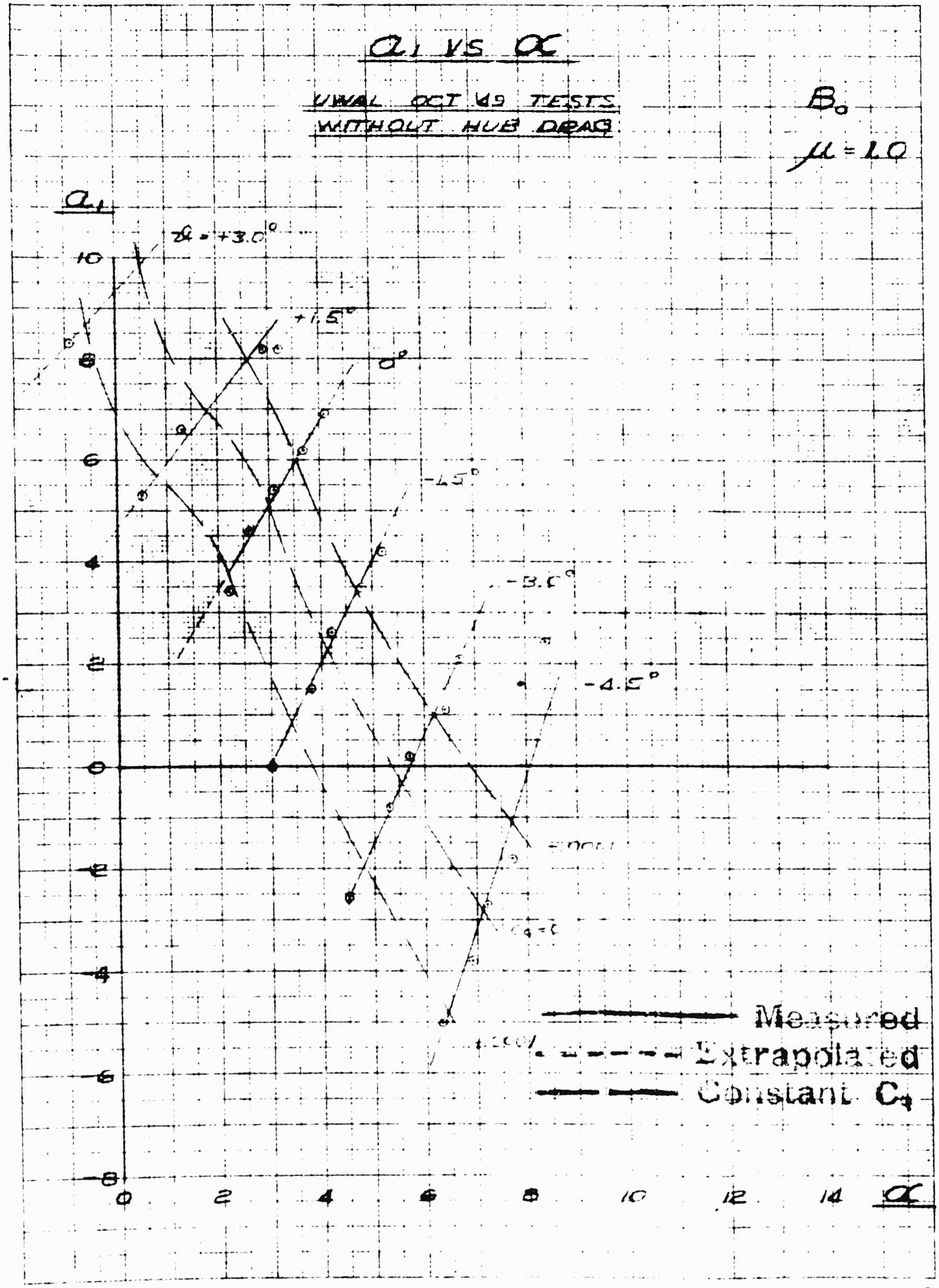

C_Q VS α
UWAL C-T '42 TESTS
WITHOUT HUB DRAG
B_0
μ = 3.0
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
θ = -1.5°
+1.5°
Measured
Extrapolated
Constant C_Q

CONFIDENTIAL

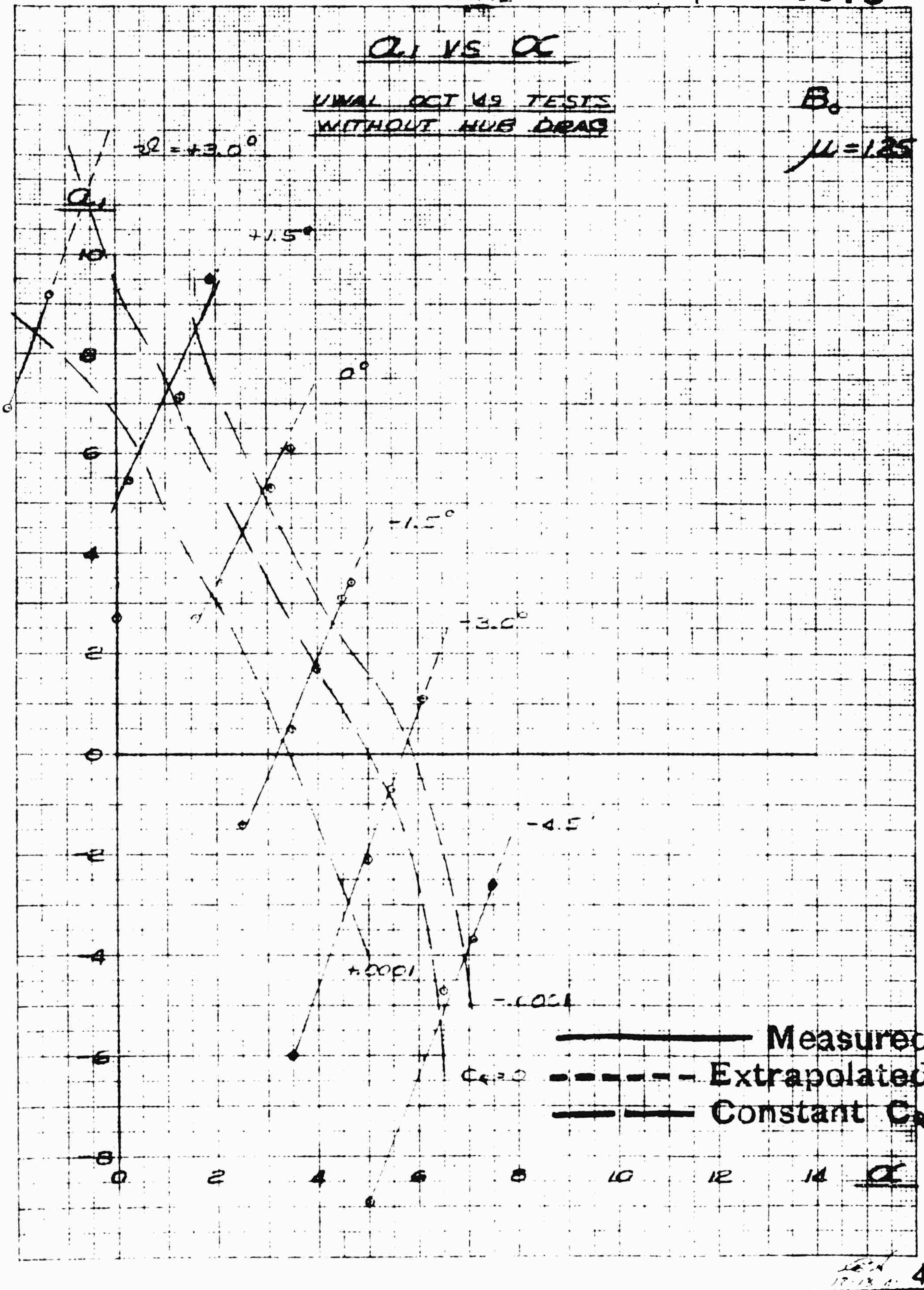




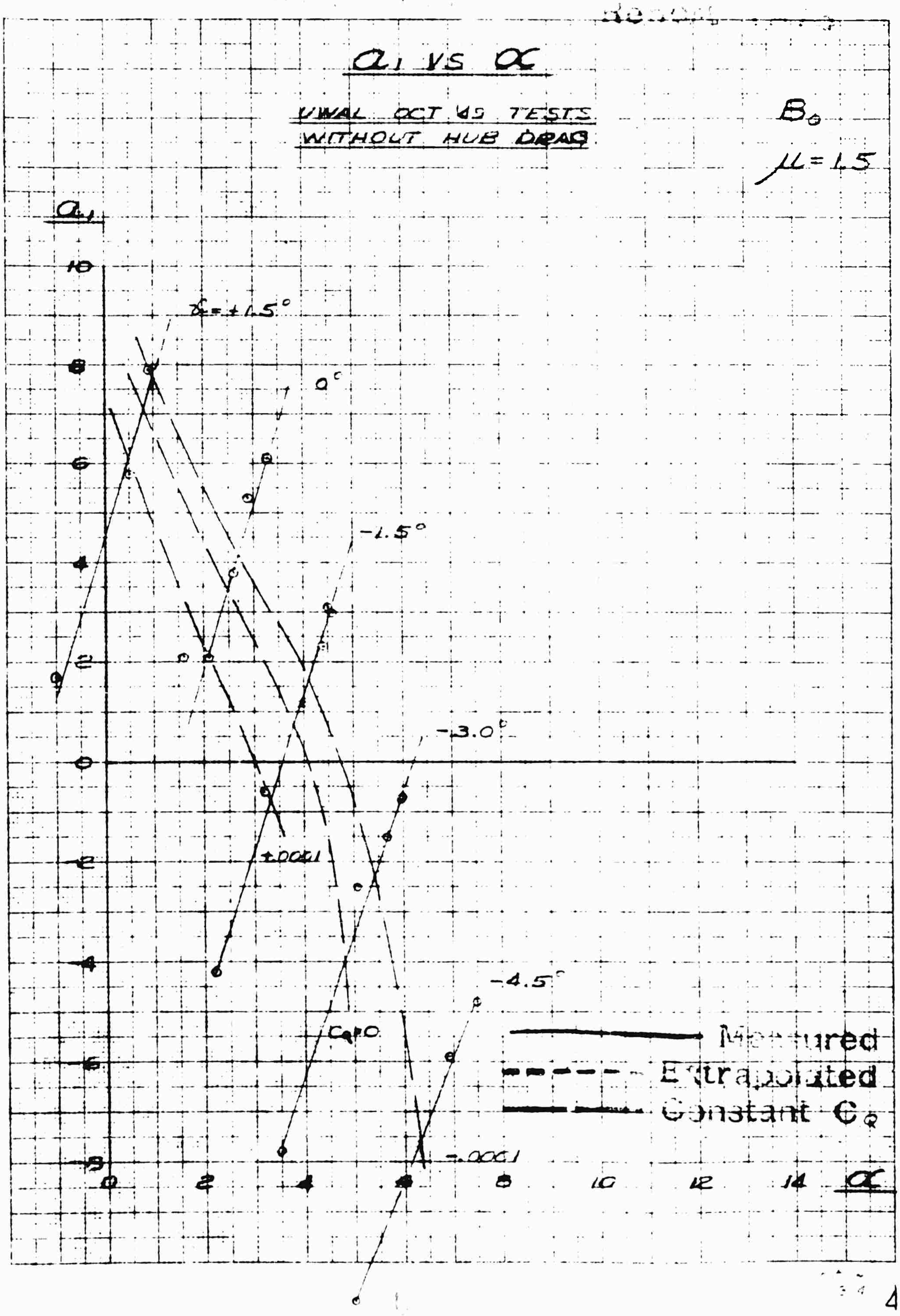
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

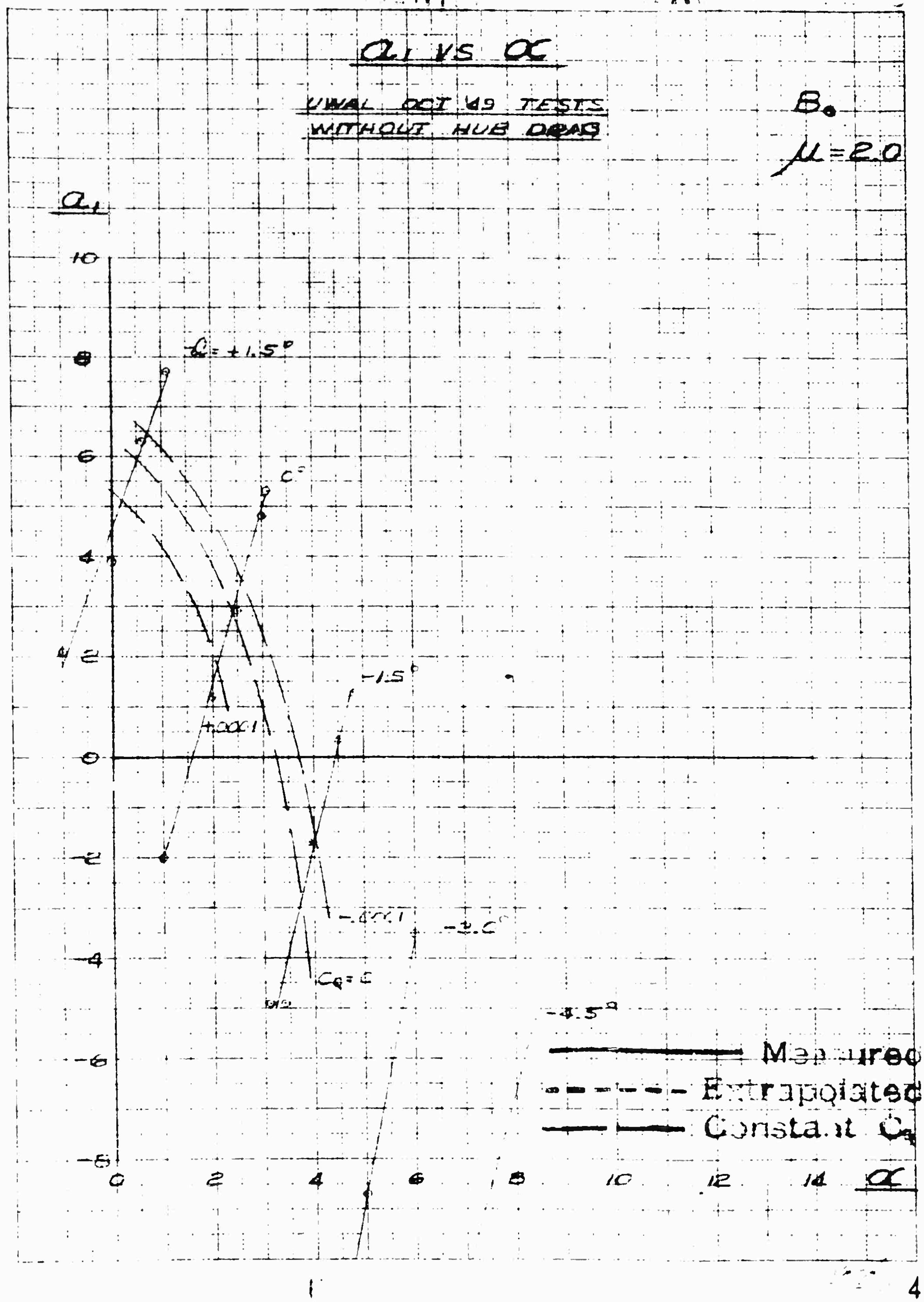


KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented

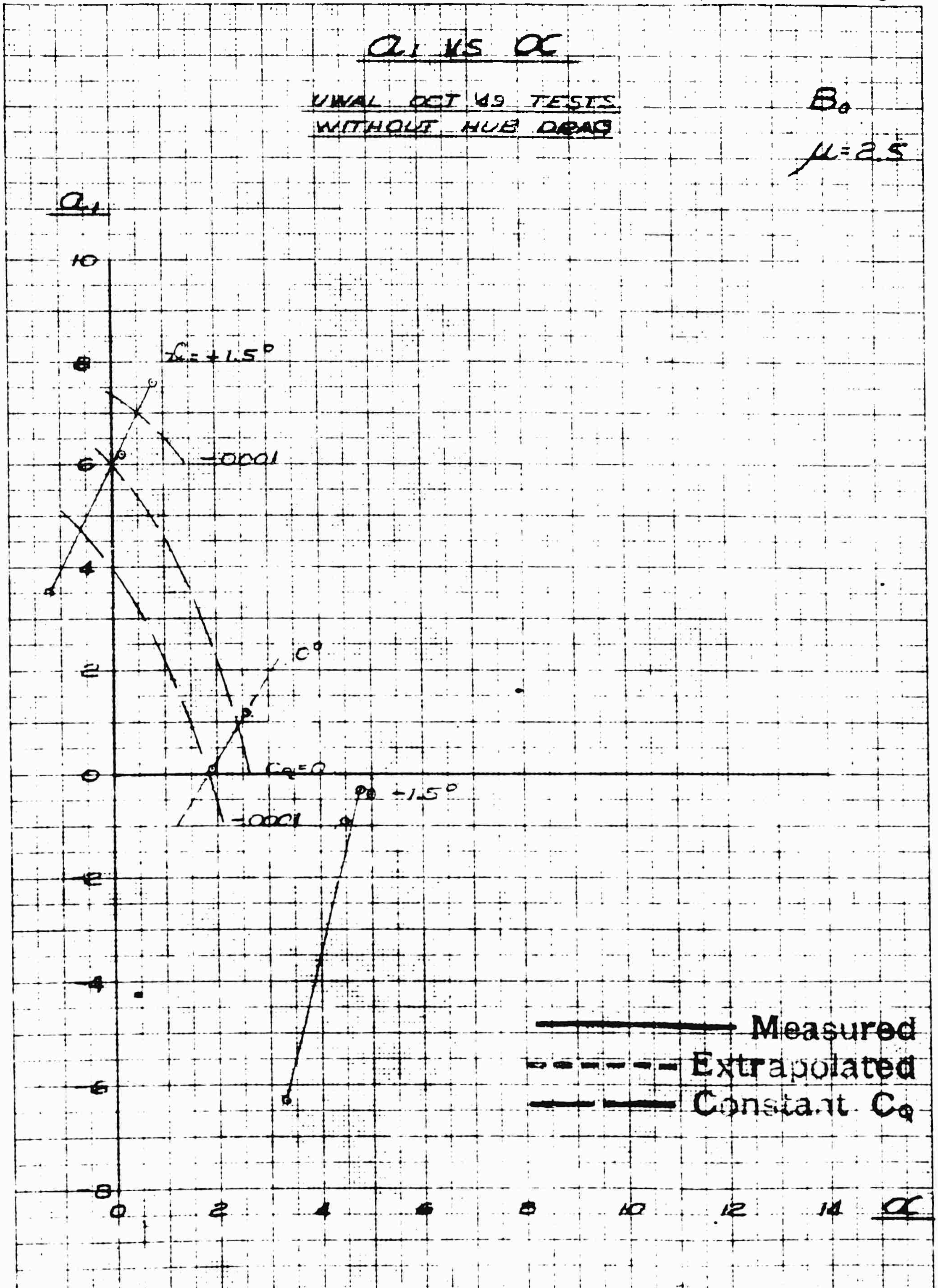


No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

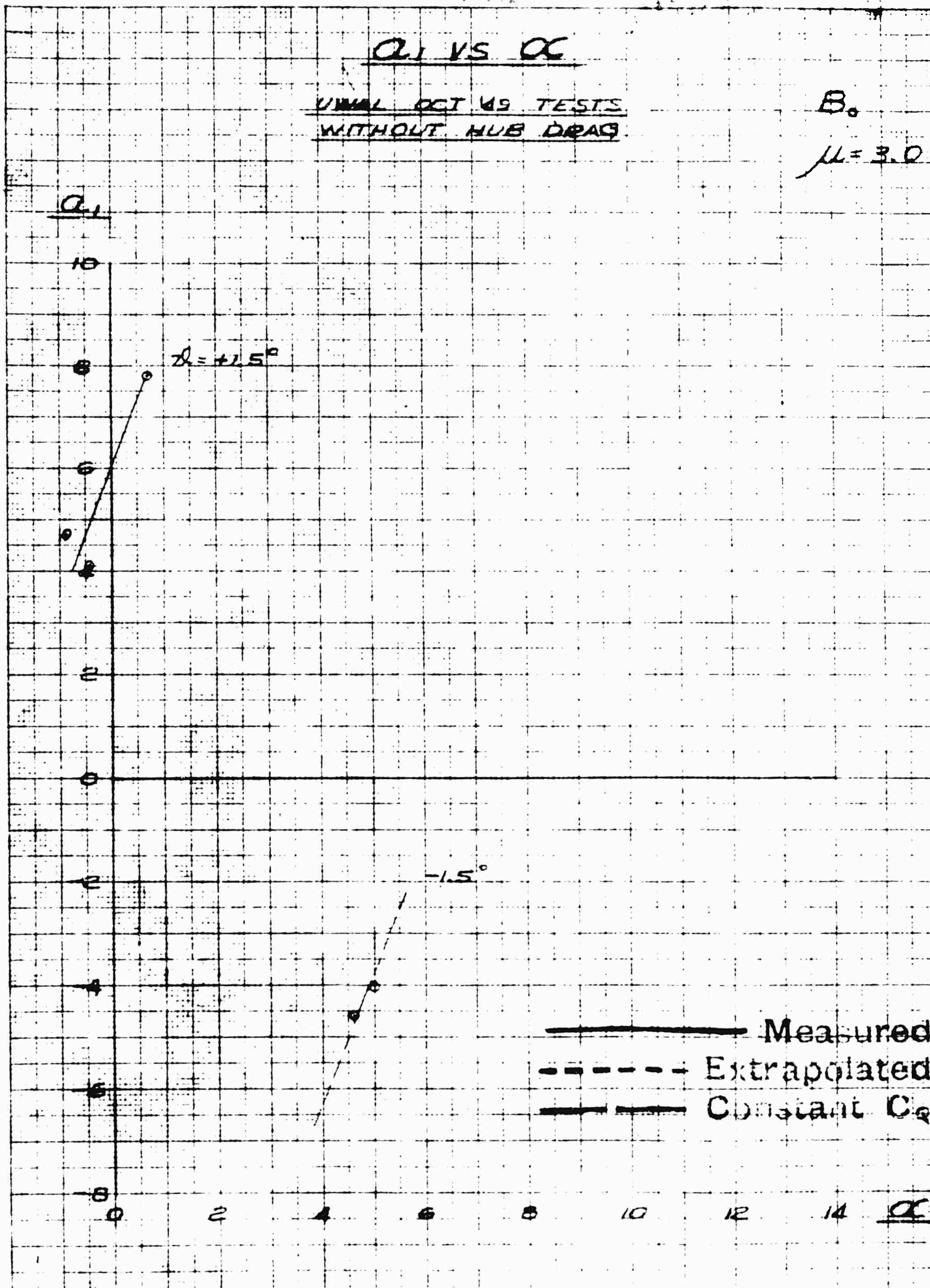
KEUFFEL & ESSER CO.



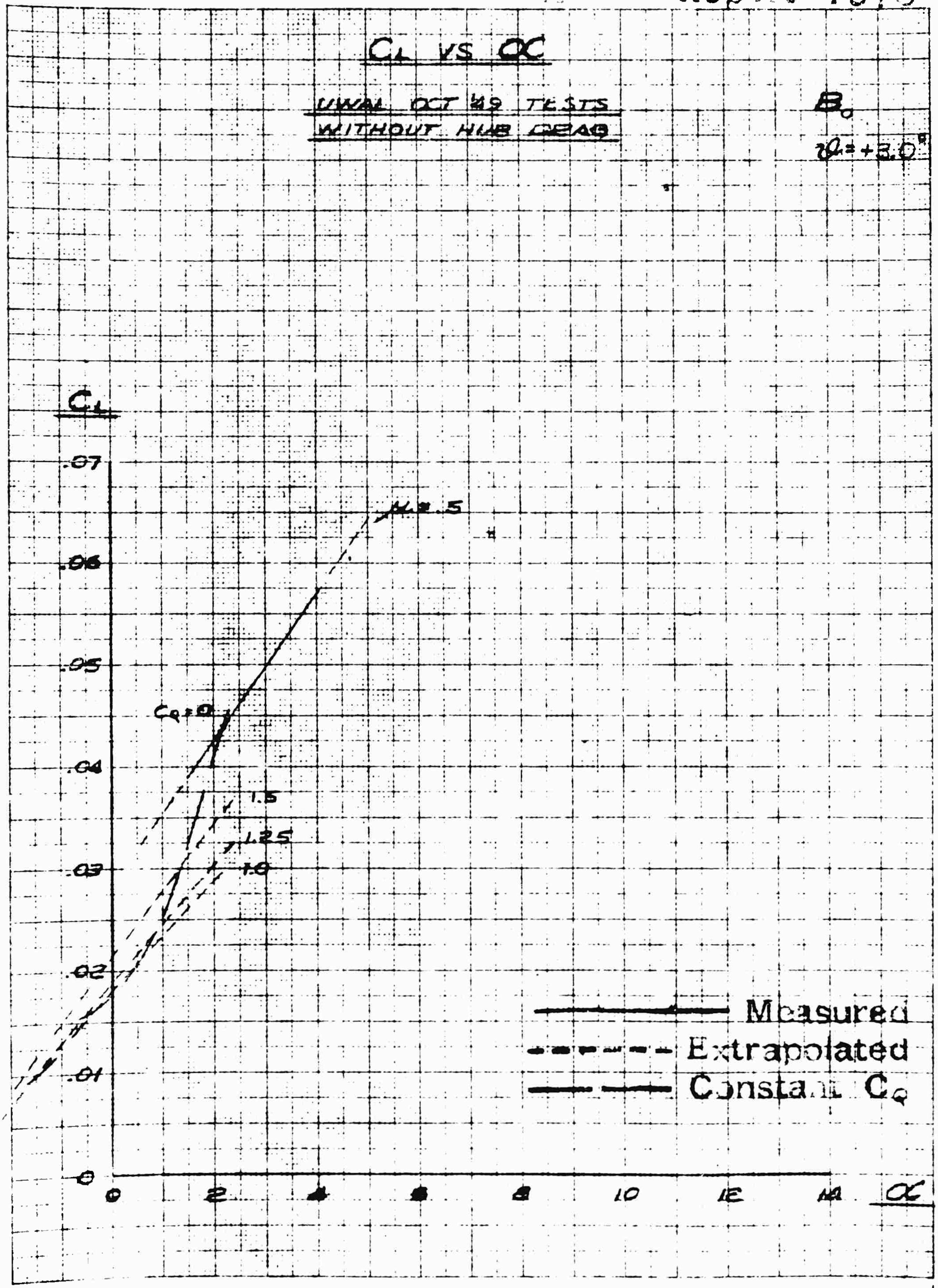
a1 VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B0
μ = 2.0
a1
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
θc = +1.5°
0°
-1.5°
-3.0°
-4.5°
+.0001
-.0001
CQ = 0
Measured
Extrapolated
Constant CQ



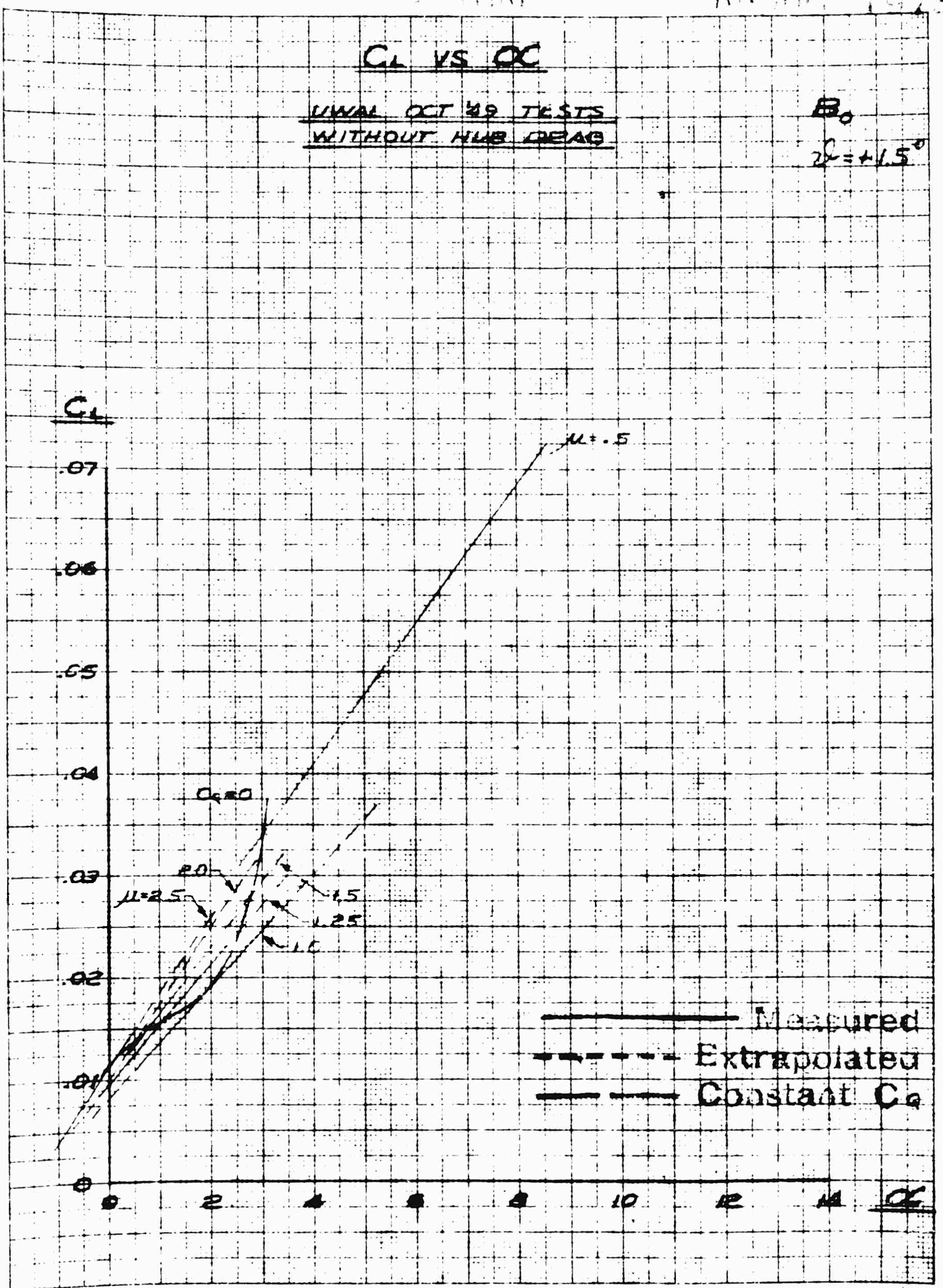
KEUFFEL & ESSER CO.
No. 359.14. Millimeters, 5 mm lines accented, cm lines heavy



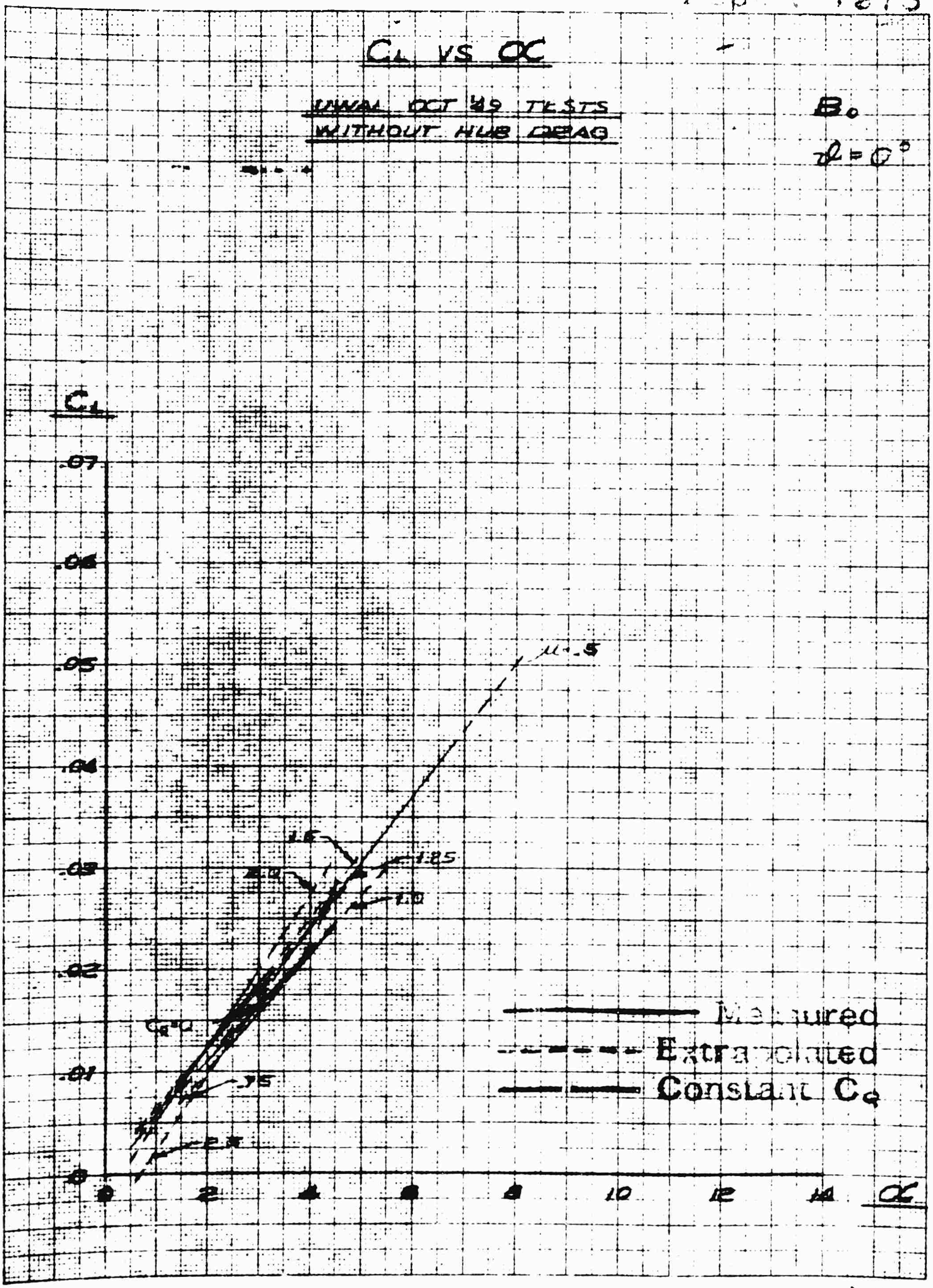
KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.



KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

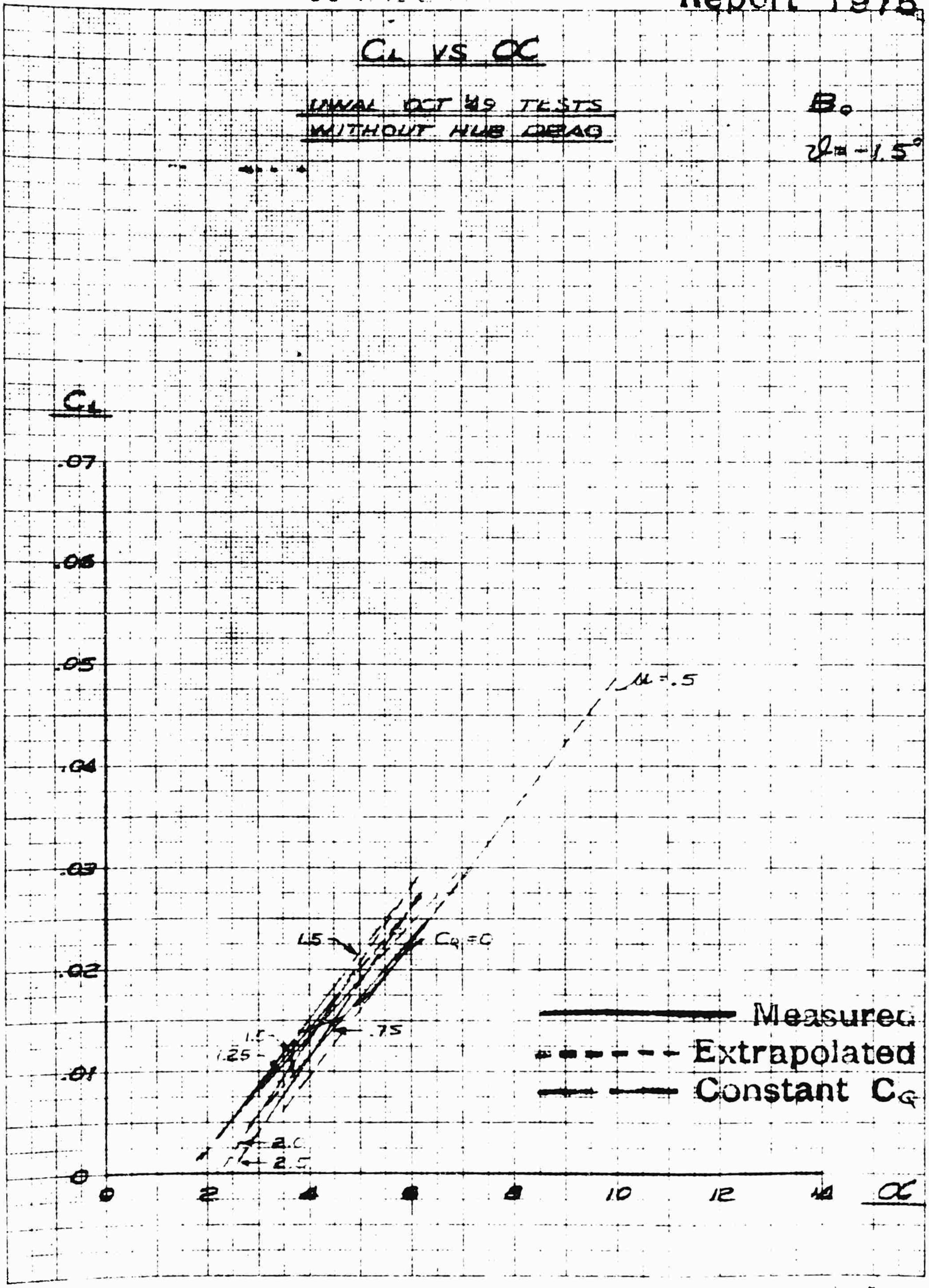


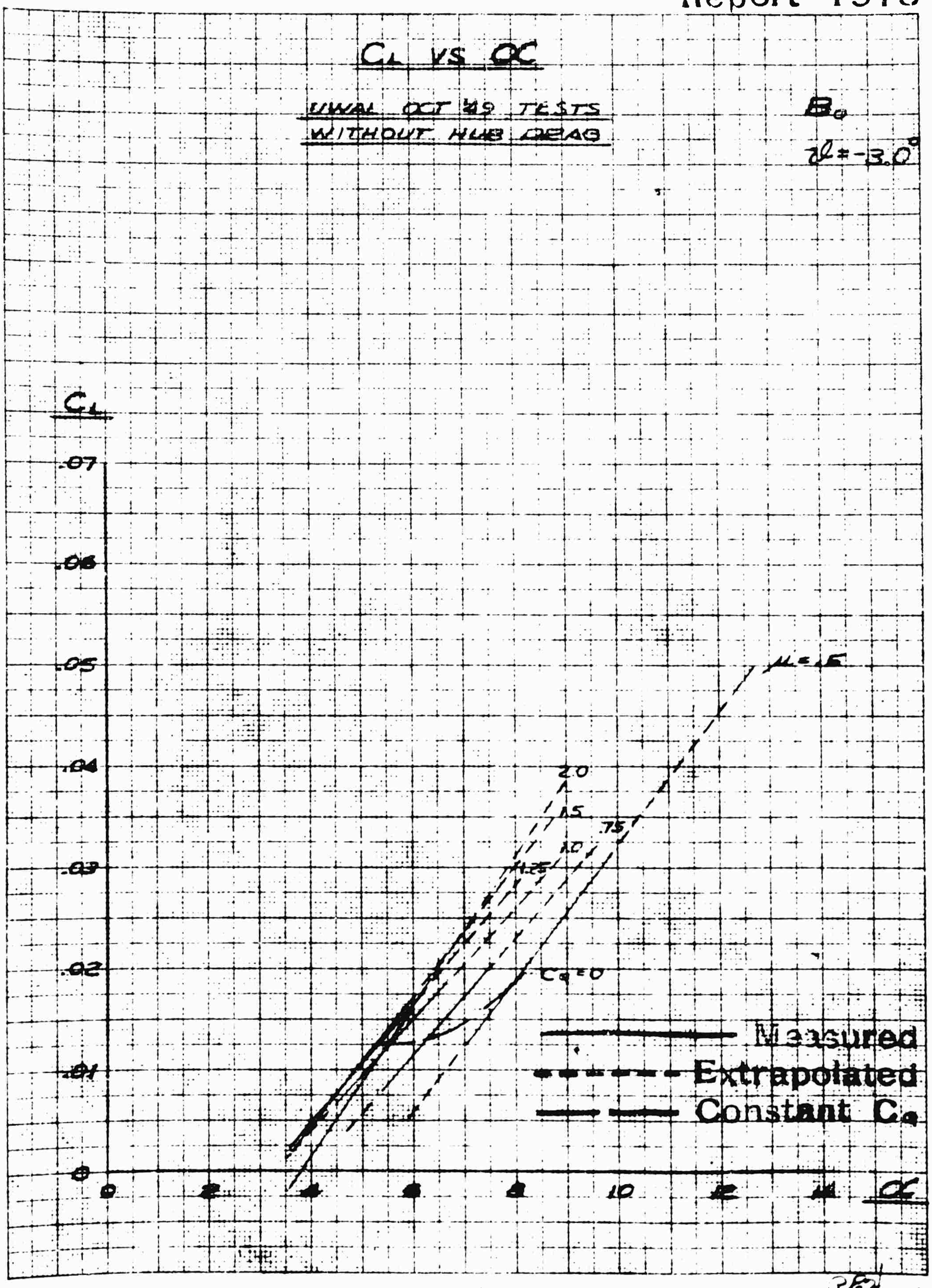
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO

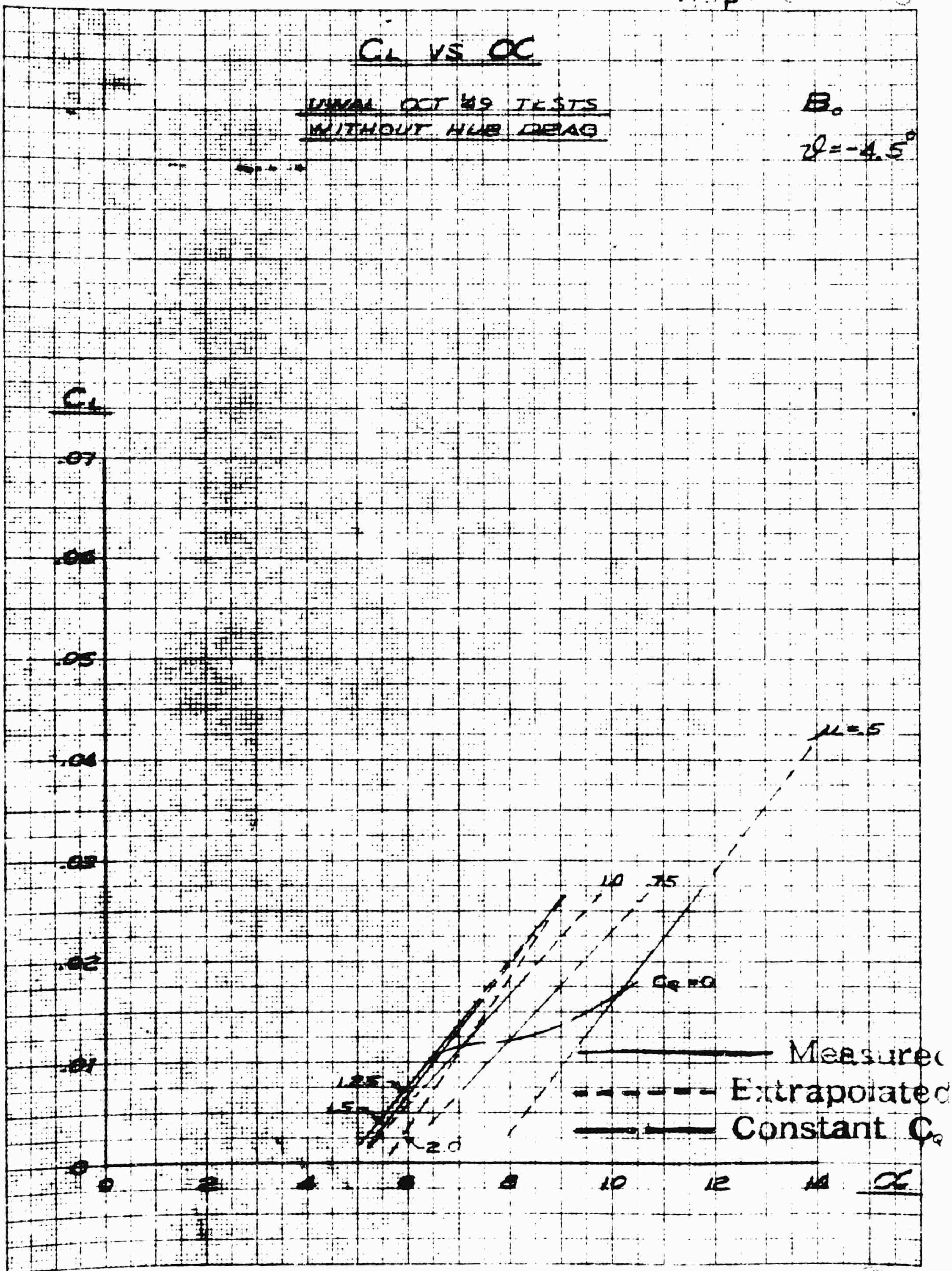


KEUFFEL & ESSER CO.

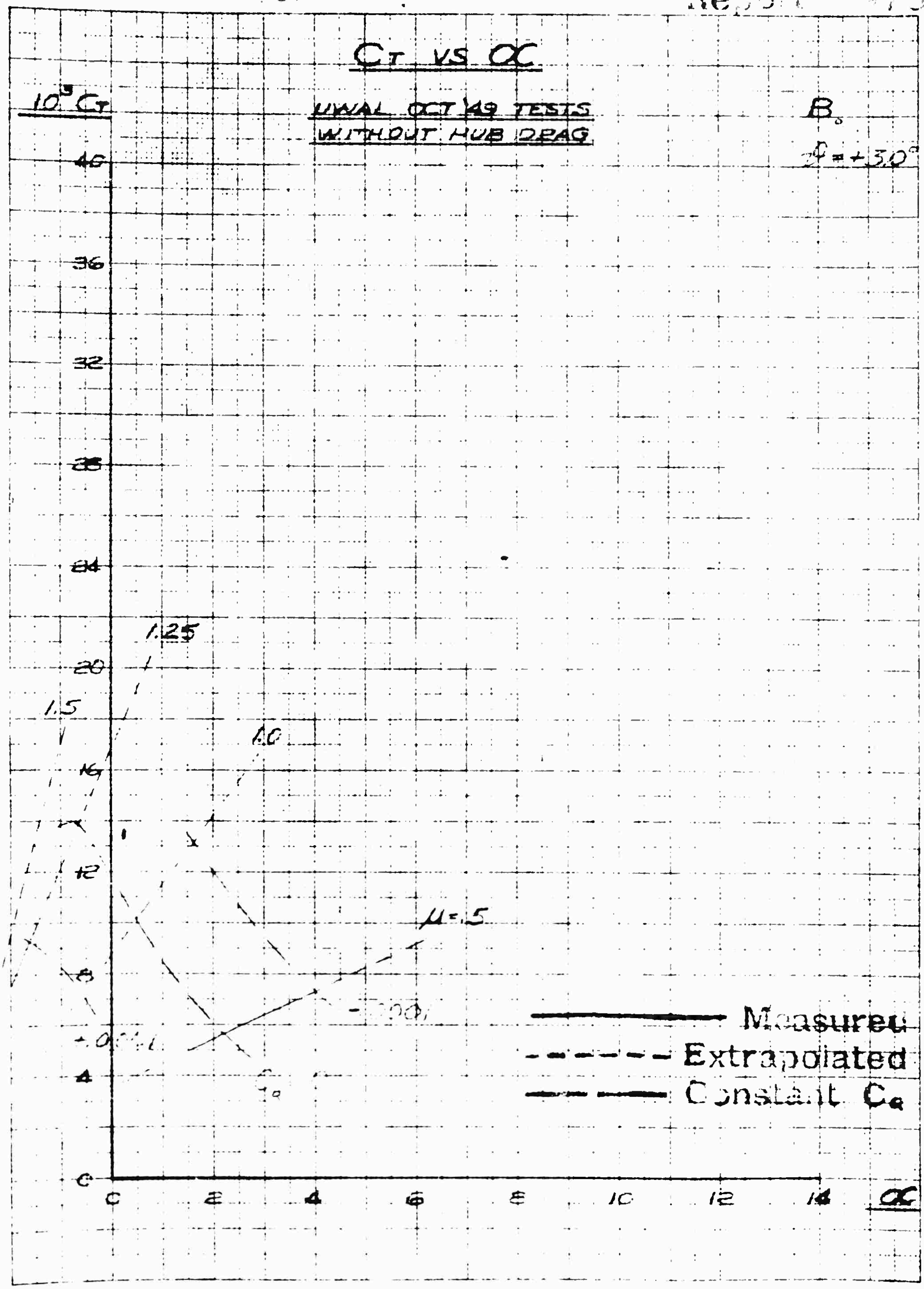
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

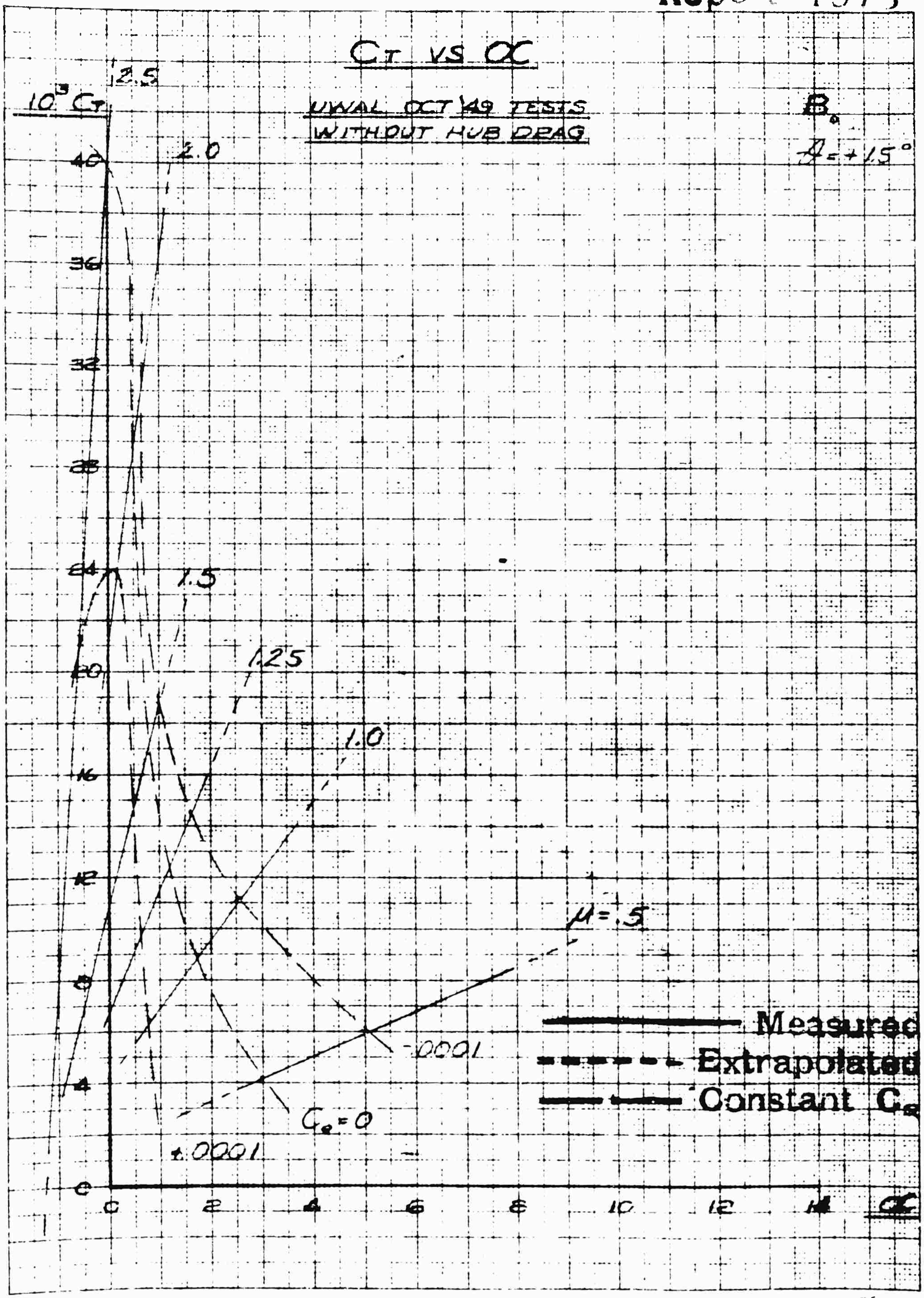

CL VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B0
θ = -1.5°
CL
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
α
μ = .5
1.5
CQ = 0
.75
1.0
1.25
2.0
2.5
Measured
Extrapolated
Constant CQ


CL VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B0
θ = -3.0°
CL
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
α
μ = .5
2.0
1.5
.75
1.0
1.25
Cq = 0
Measured
Extrapolated
Constant Cq

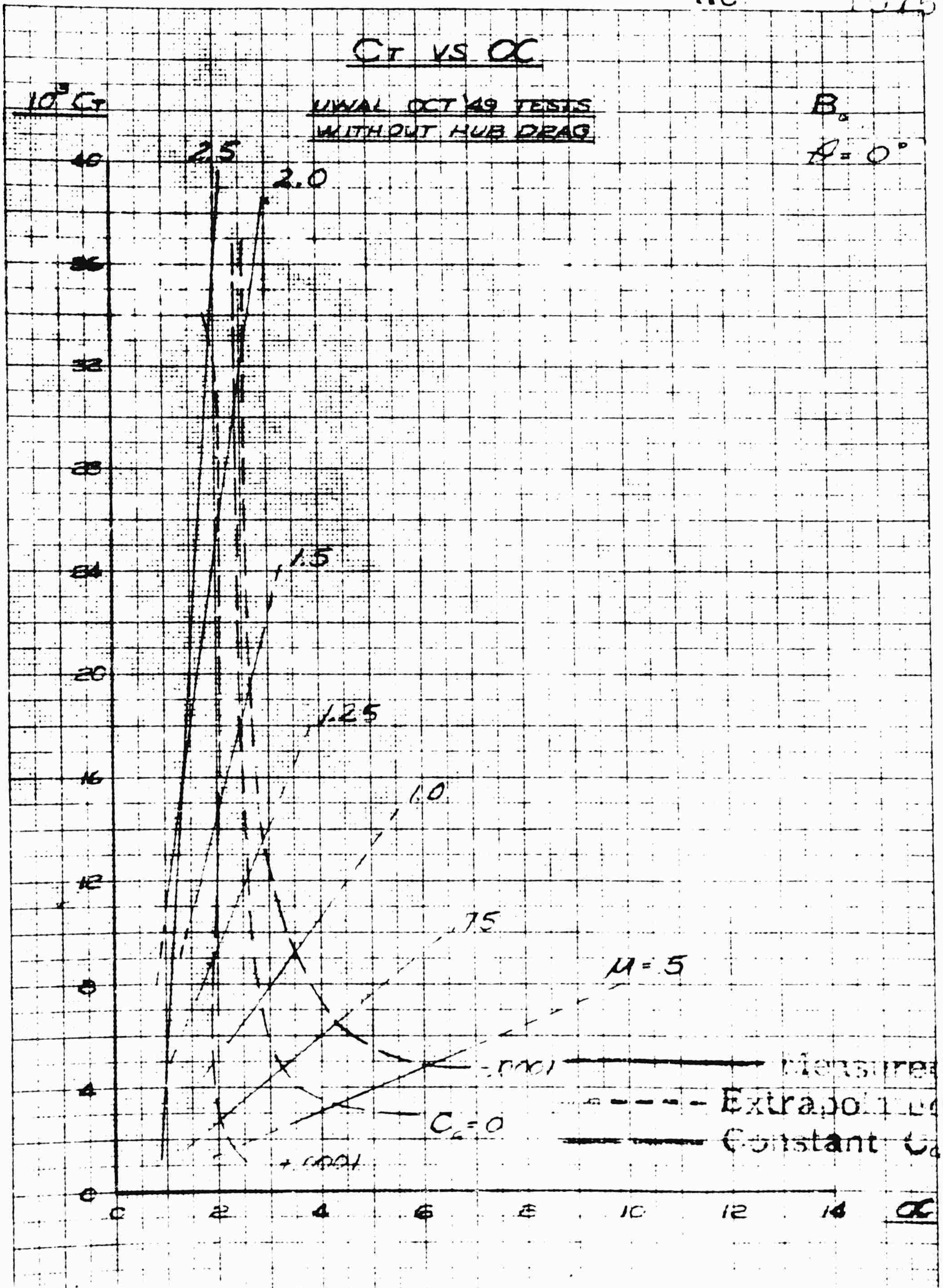


CL VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B₀
θ = -4.5°
CL
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
α
μ=.5
1.0
.75
1.25
1.5
2.0
CQ=0
Measured
Extrapolated
Constant CQ

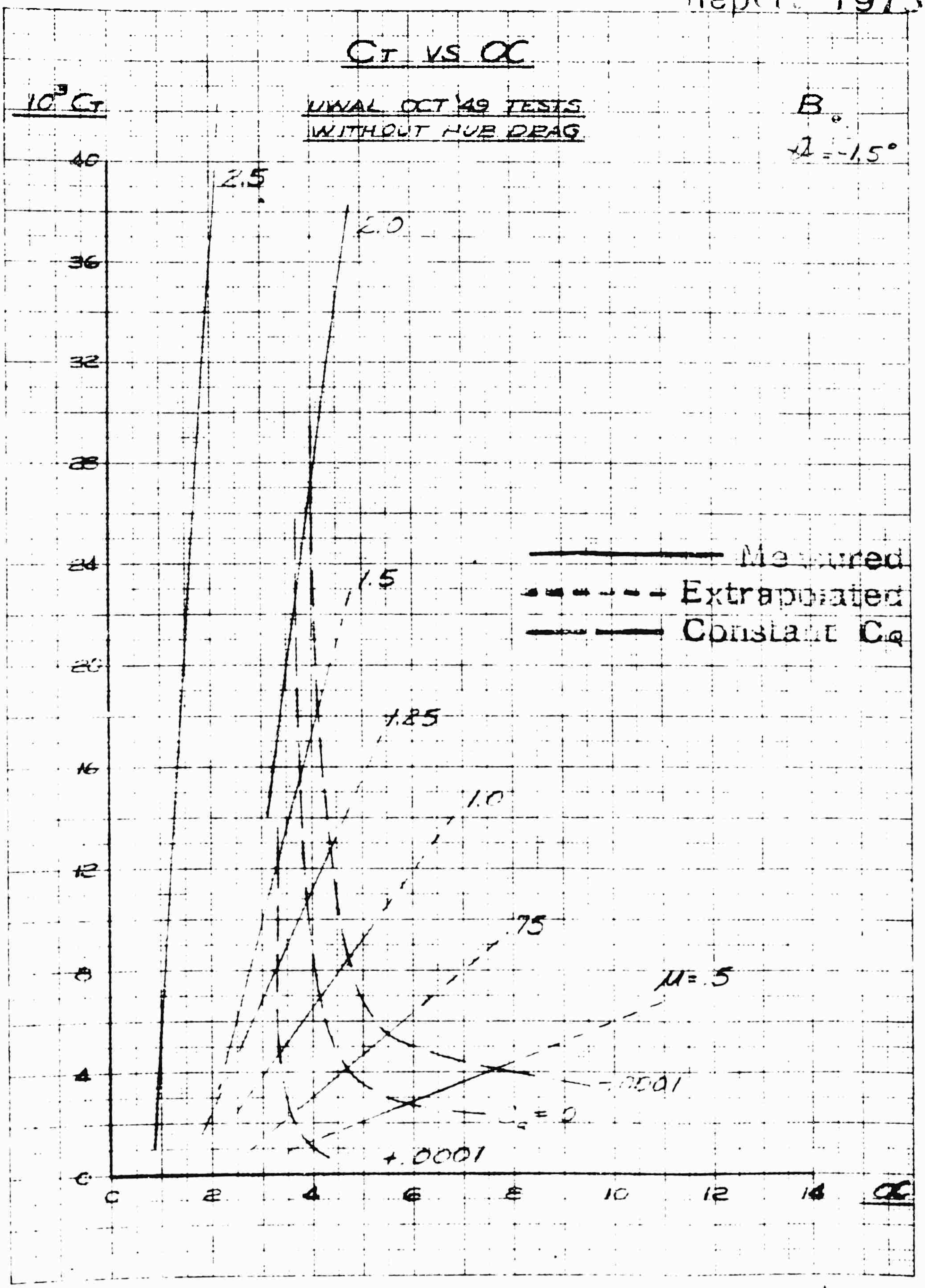

CT VS α
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\theta = +3.0°$
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
α
1.25
1.5
1.0
μ=.5
Measured
Extrapolated
Constant C_Q

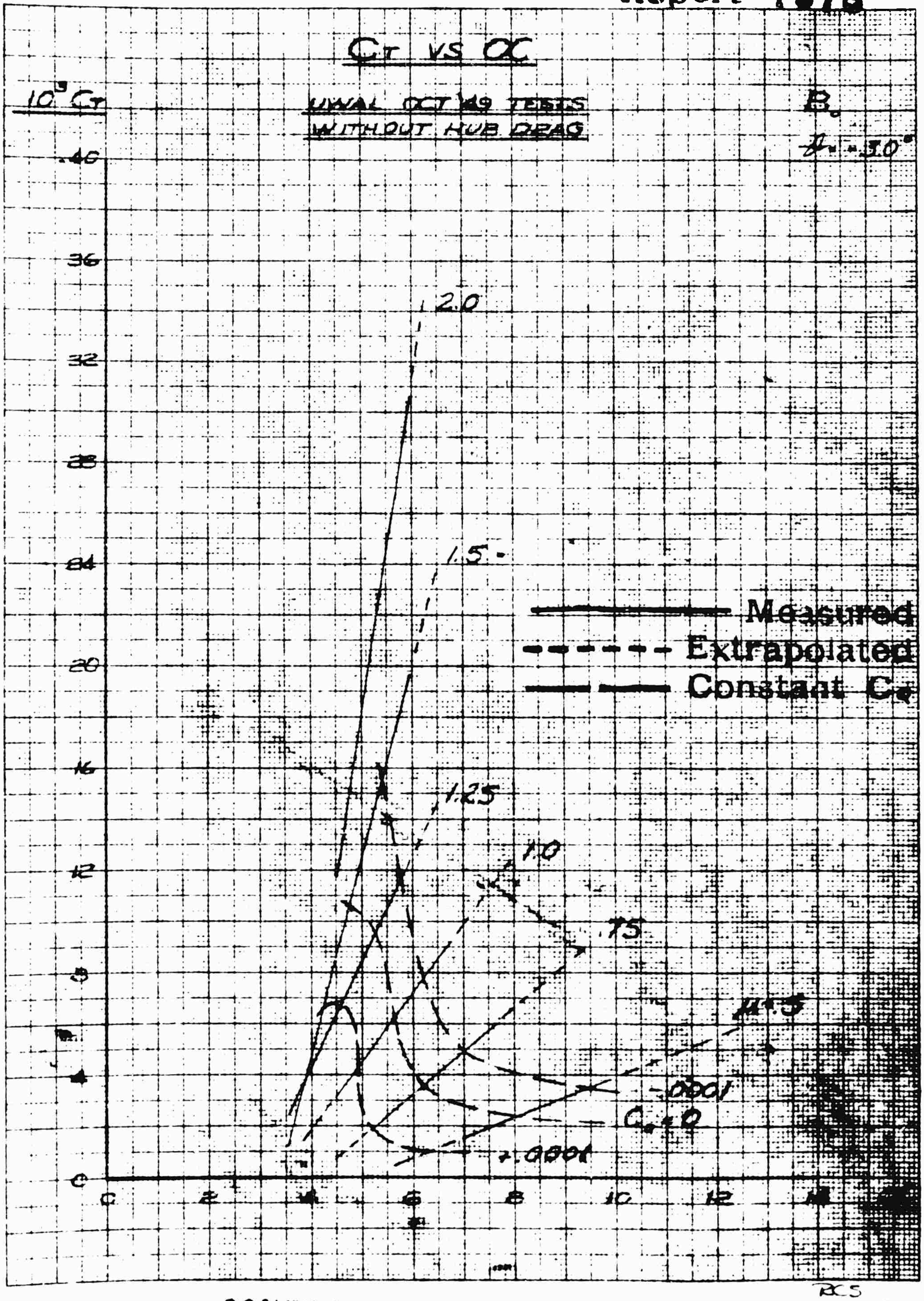


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

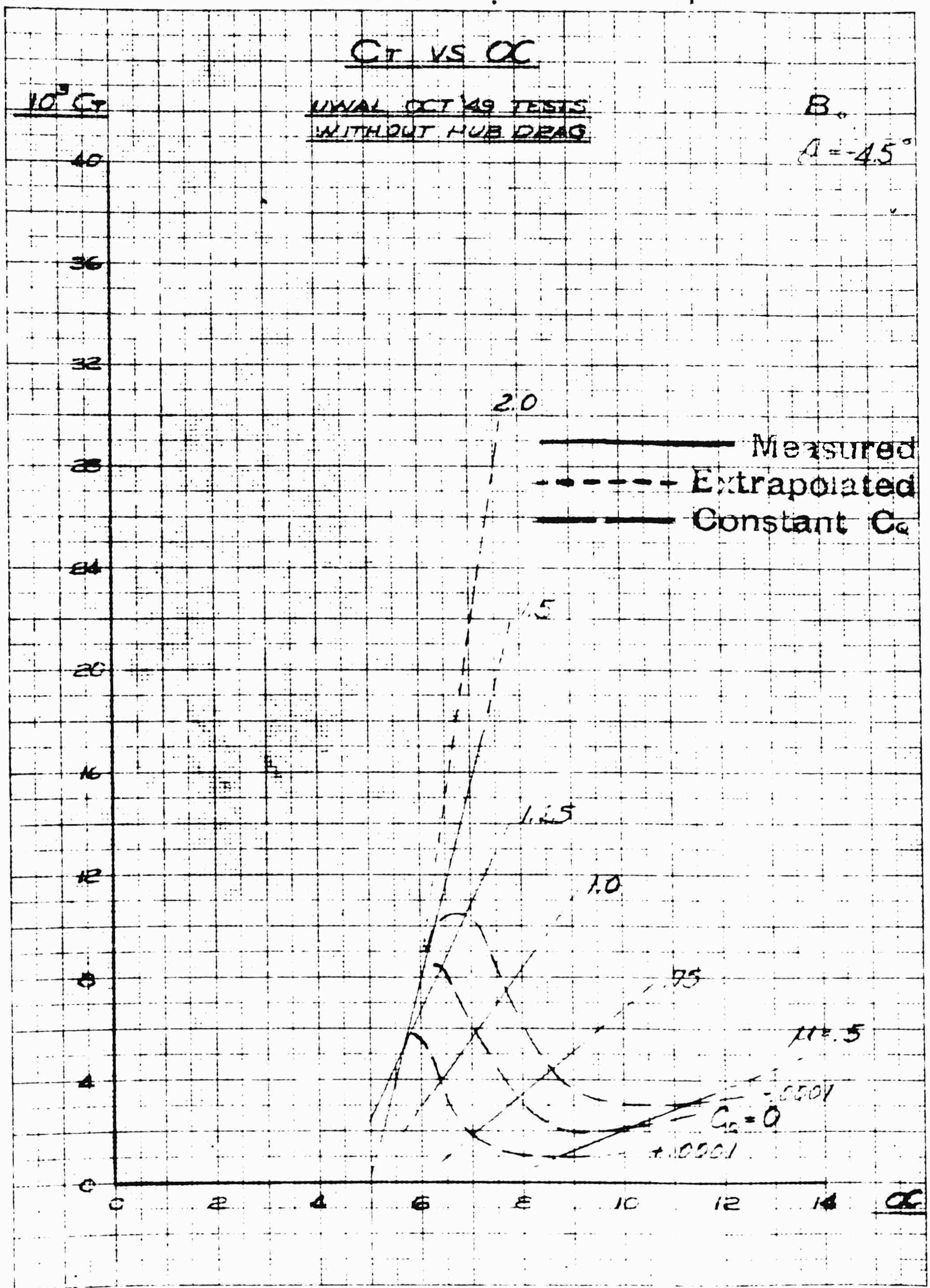

CT VS α
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
-1.5°
40
36
32
28
24
20
16
12
8
4
0
0
2
4
6
8
10
12
14
α
2.5
2.0
1.5
1.25
1.0
.75
μ = .5
Measured
Extrapolated
Constant C_Q
-.0001
C_Q = 0
+.0001



RCS
12-14-49
55

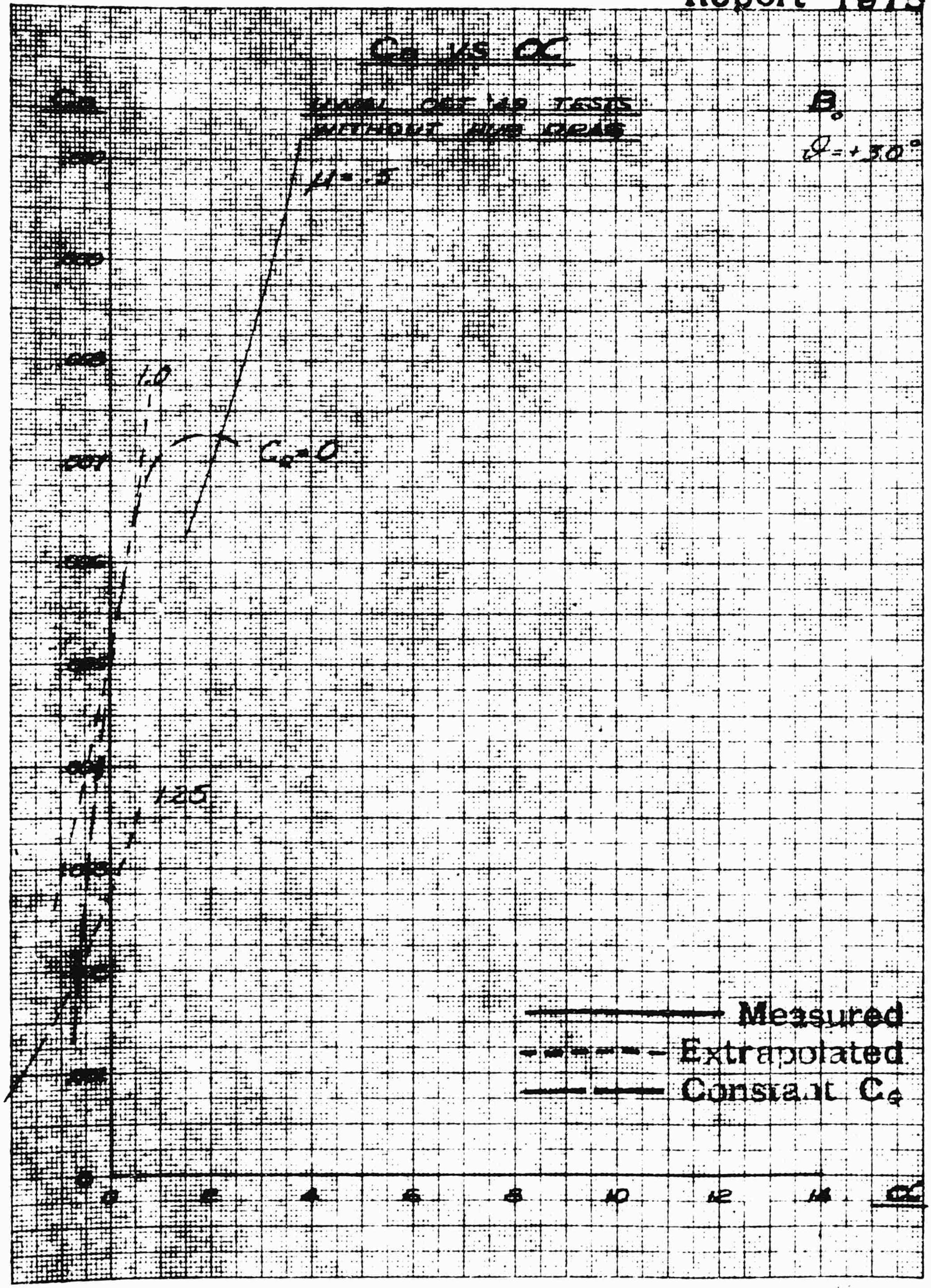
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

CONFIDENTIAL



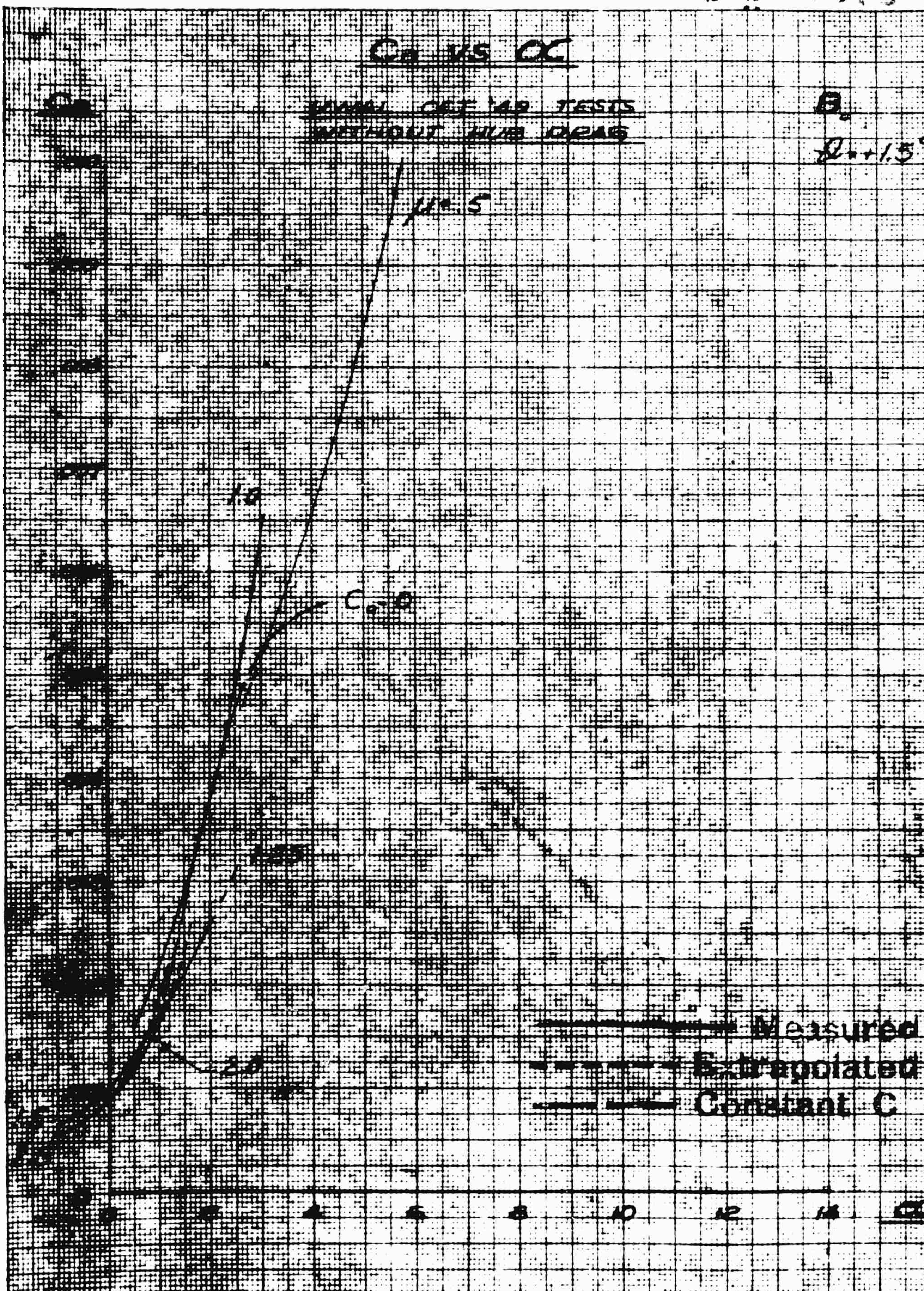
KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



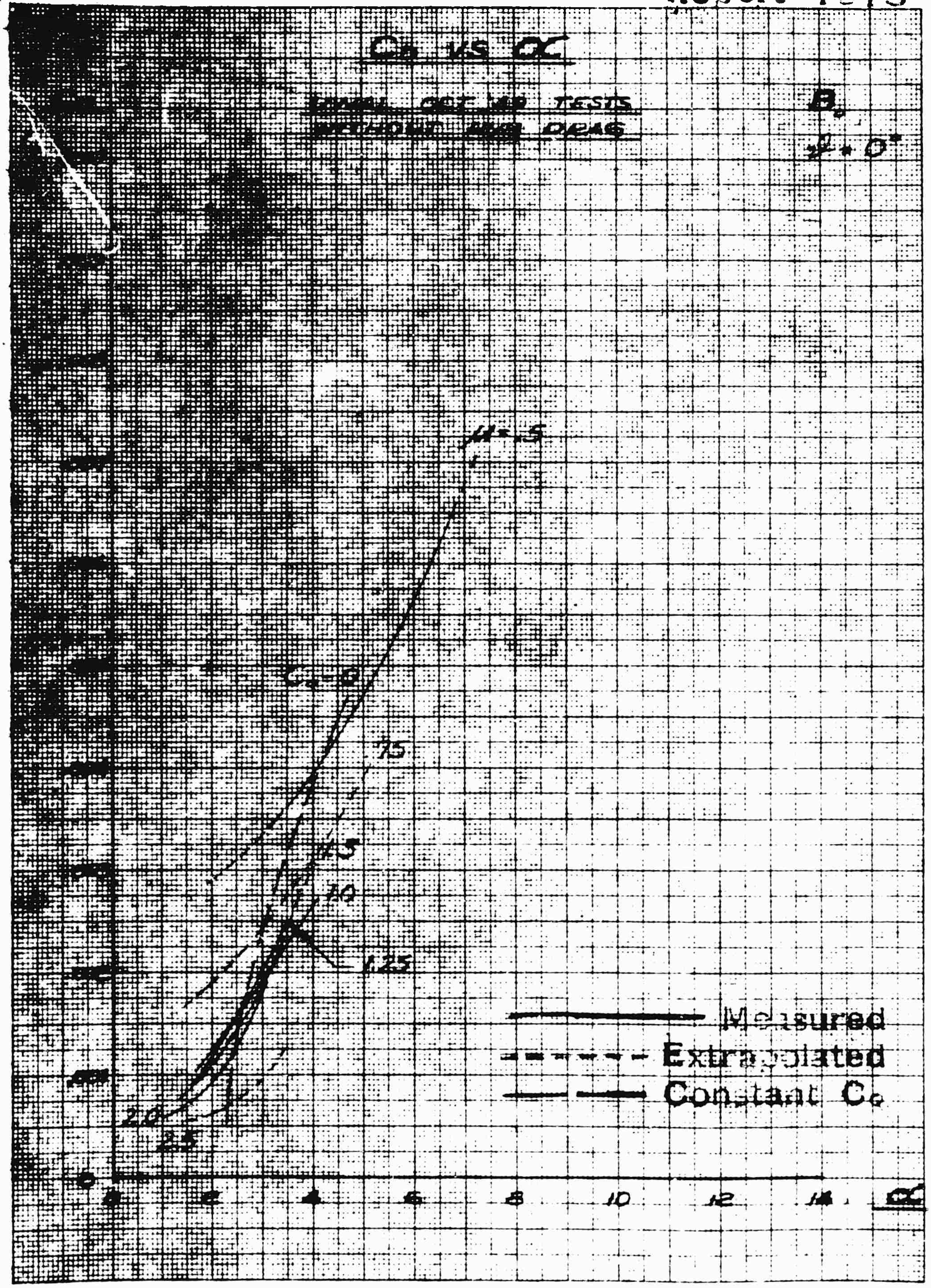
KEUFFEL & ESSER CO.

No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy.

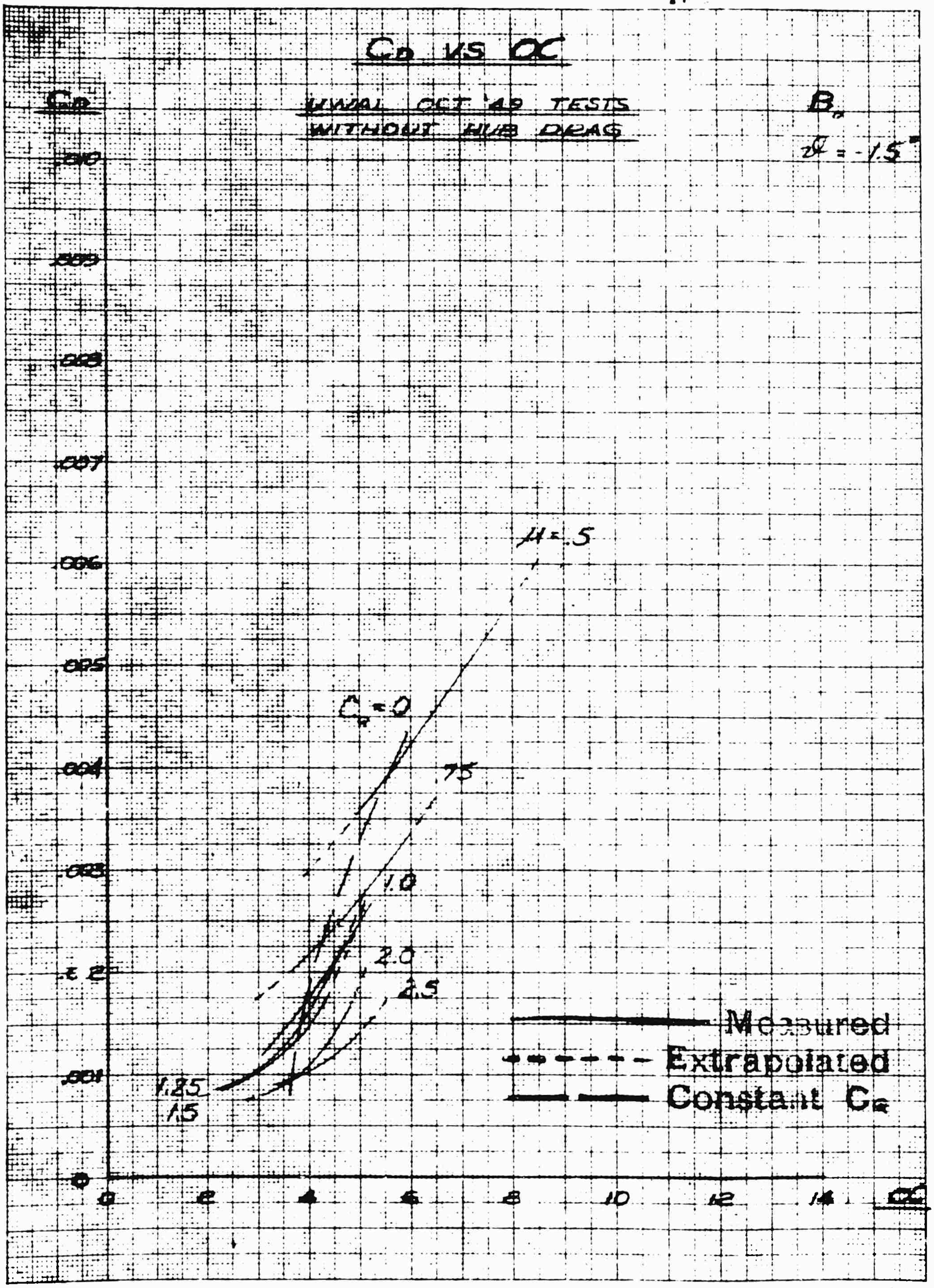
CONFIDENTIAL

FCC 12-14-49

CONFIDENTIAL

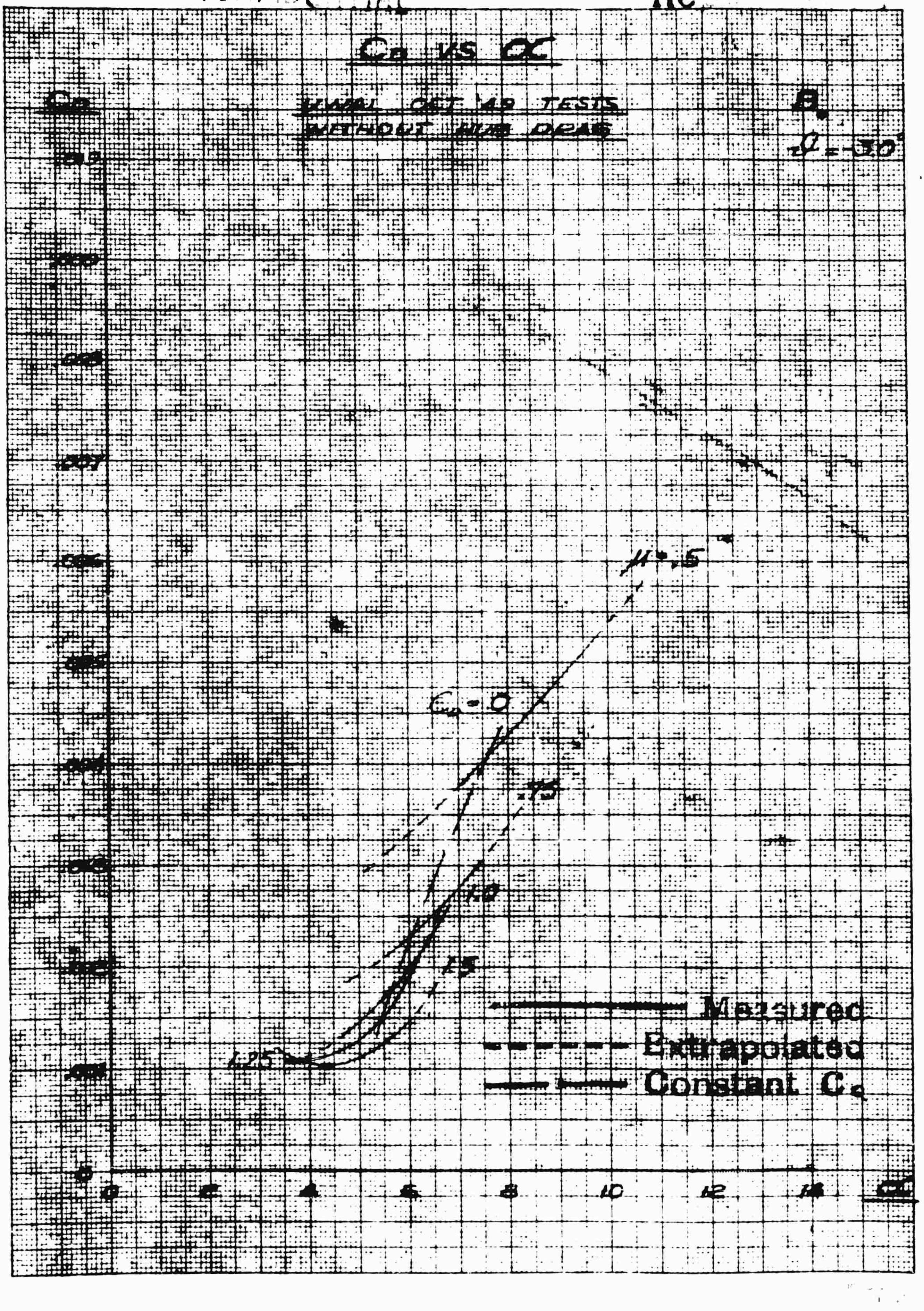


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.

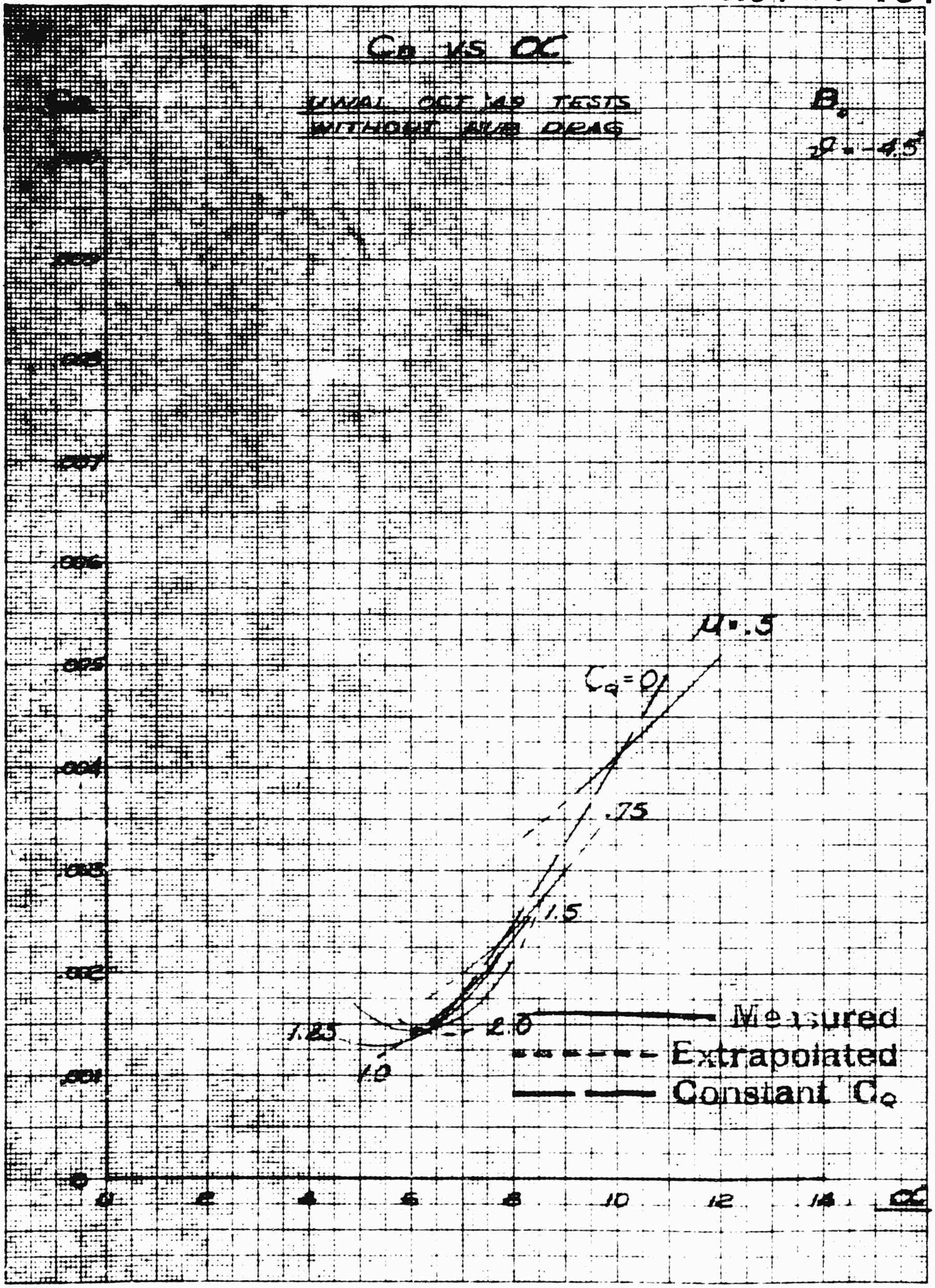


KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

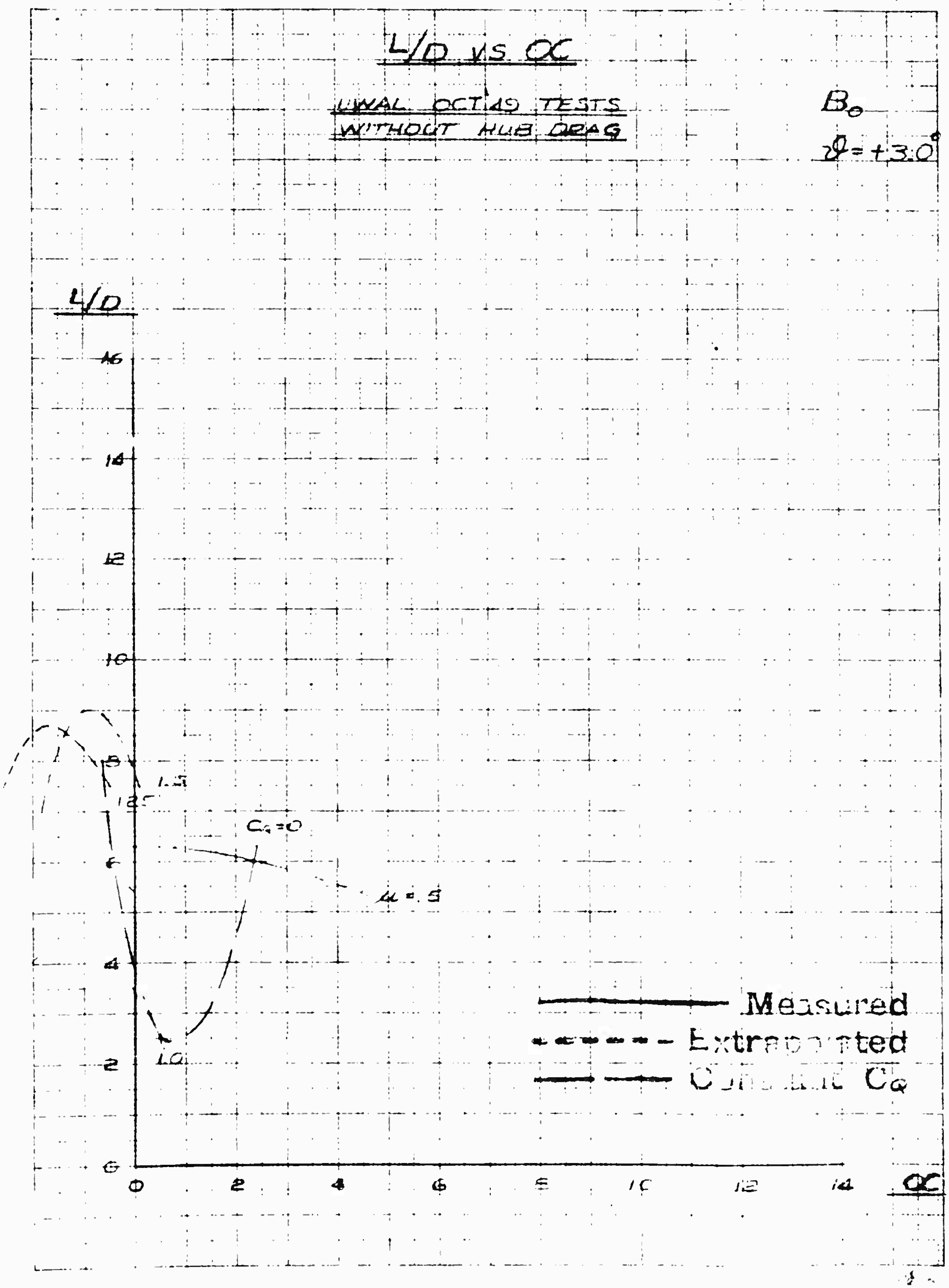


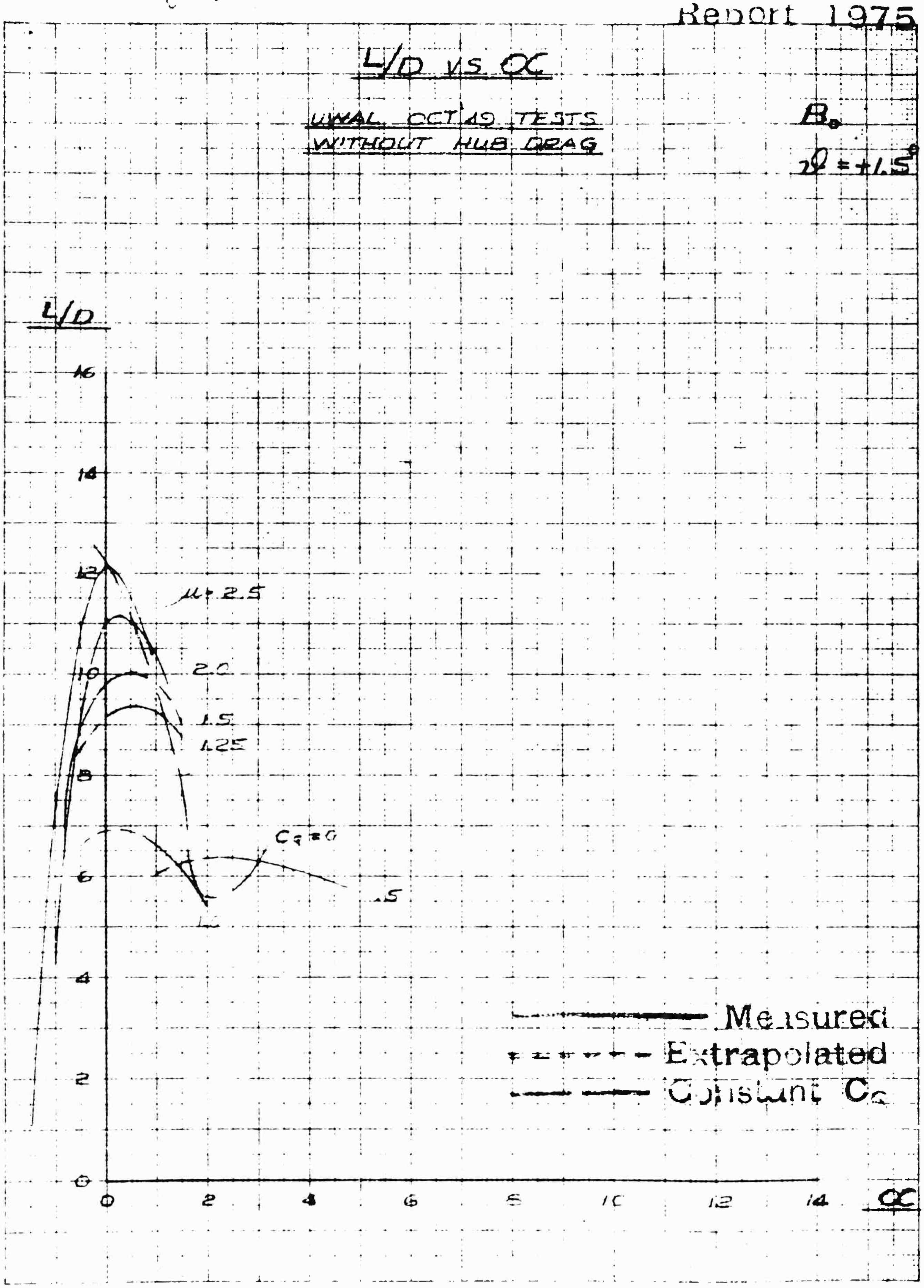
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
MADE IN U.S.A.



KEUFFEL & ESSER CO.

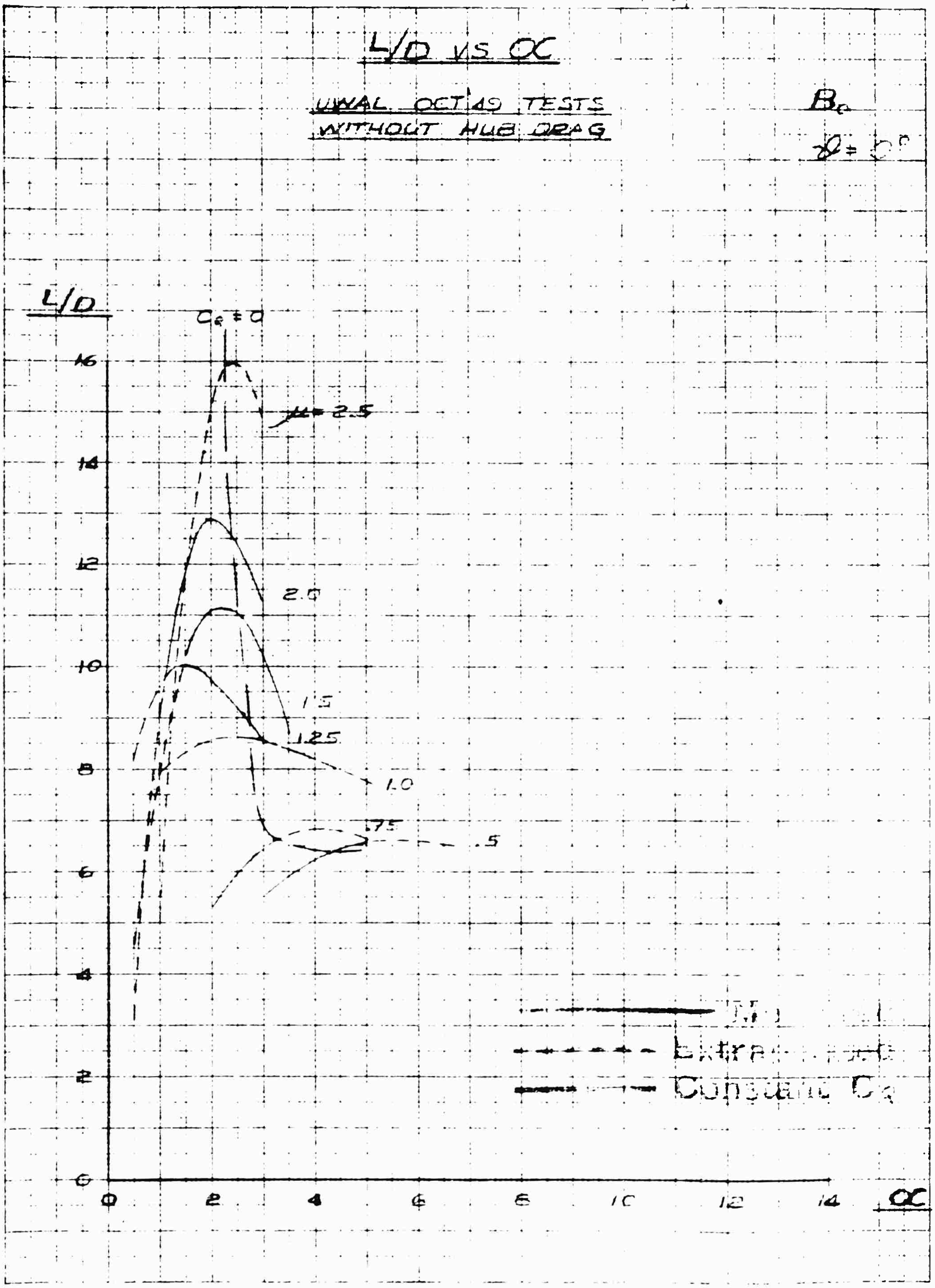
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.


L/D VS QC
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B_0
$\vartheta = +3.0°$
L/D
16
14
12
10
8
6
4
2
0
1.5
1.25
$C_Q = 0$
$\mu = .5$
1.0
0
2
4
6
8
10
12
14
QC
Measured
Extrapolated
Constant C_Q



KEUFFEL & ESSER CO.

CONF...

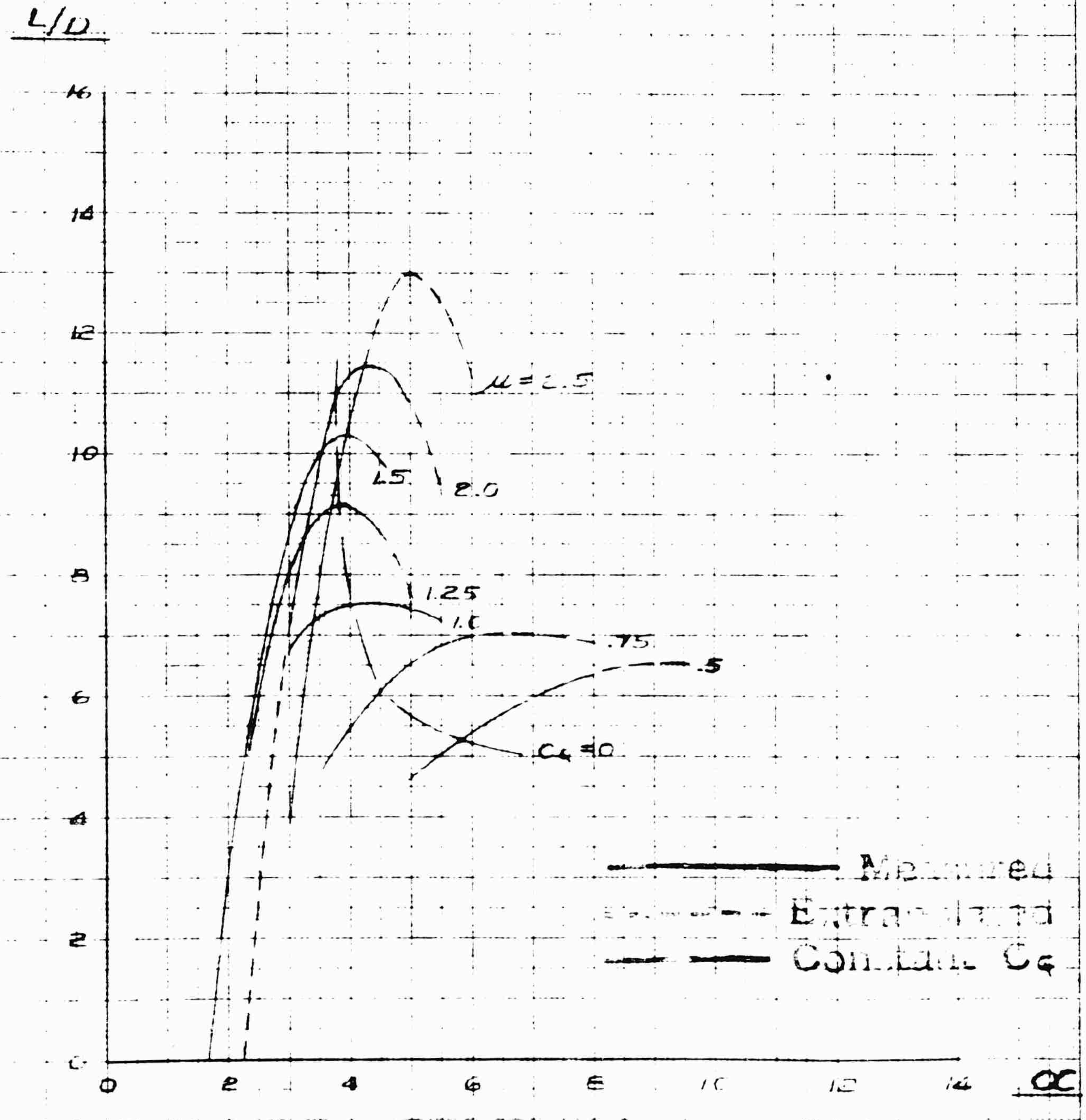


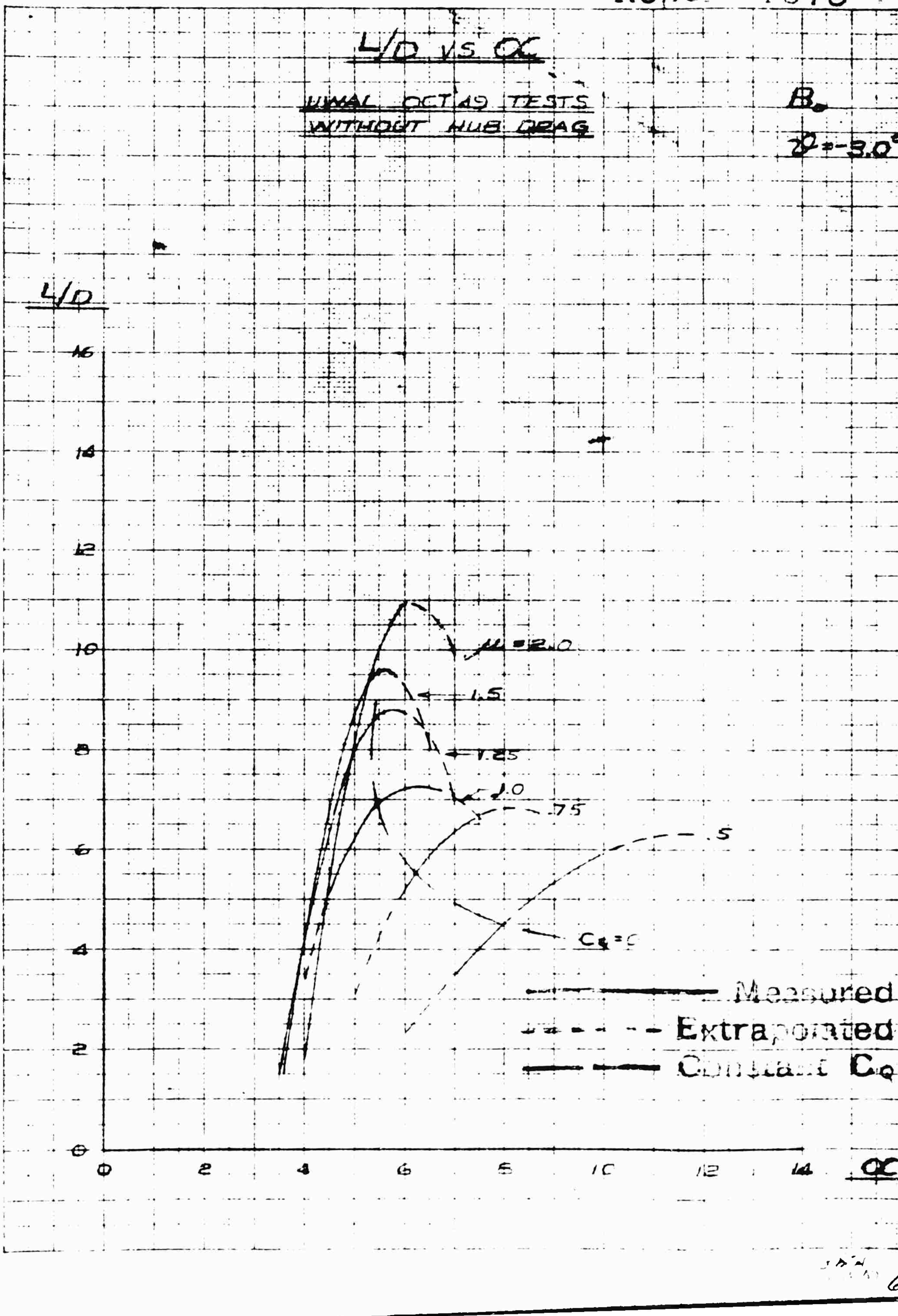
KEUFFEL & ESSER CO.
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy

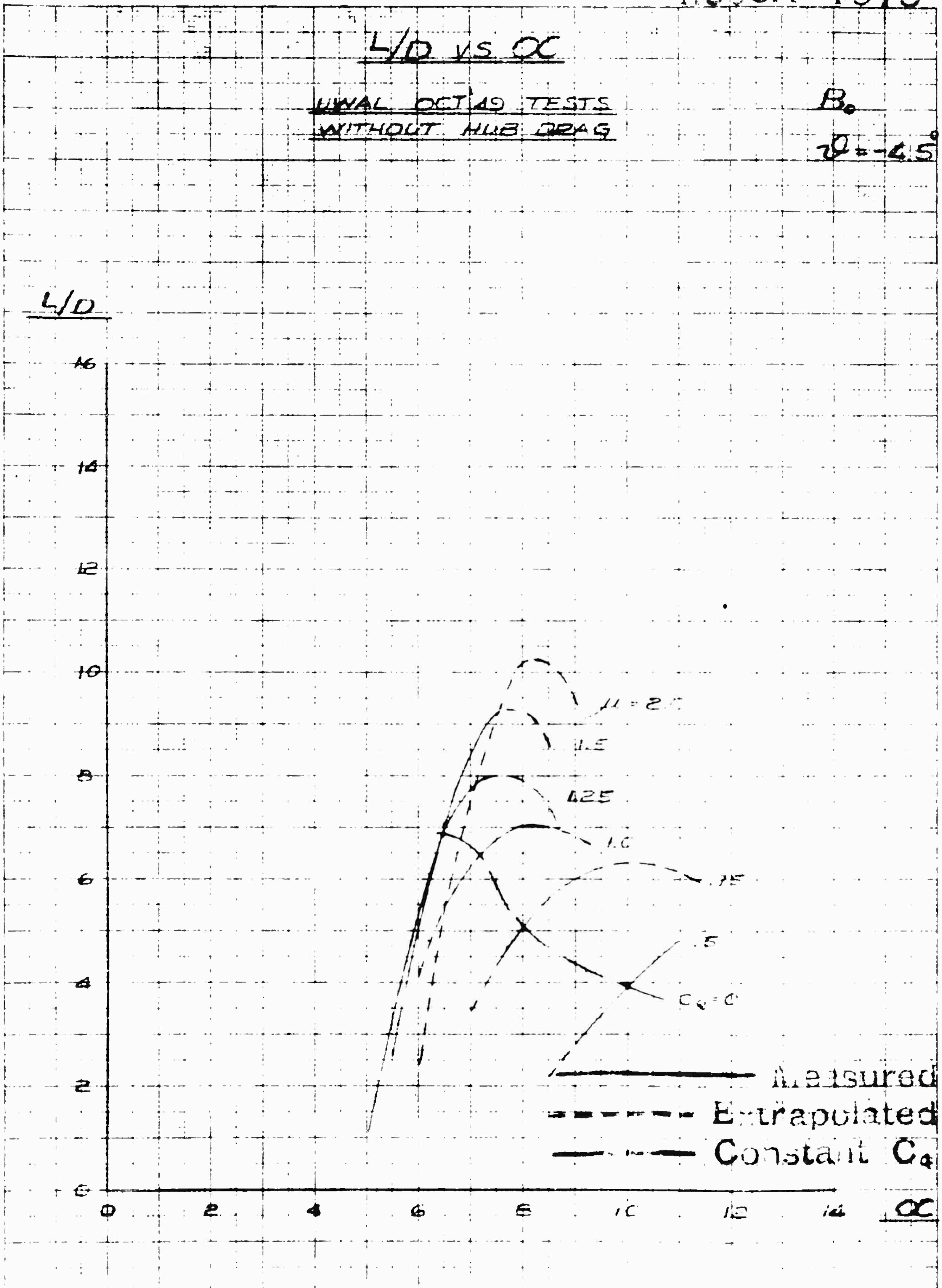
L/D vs. α

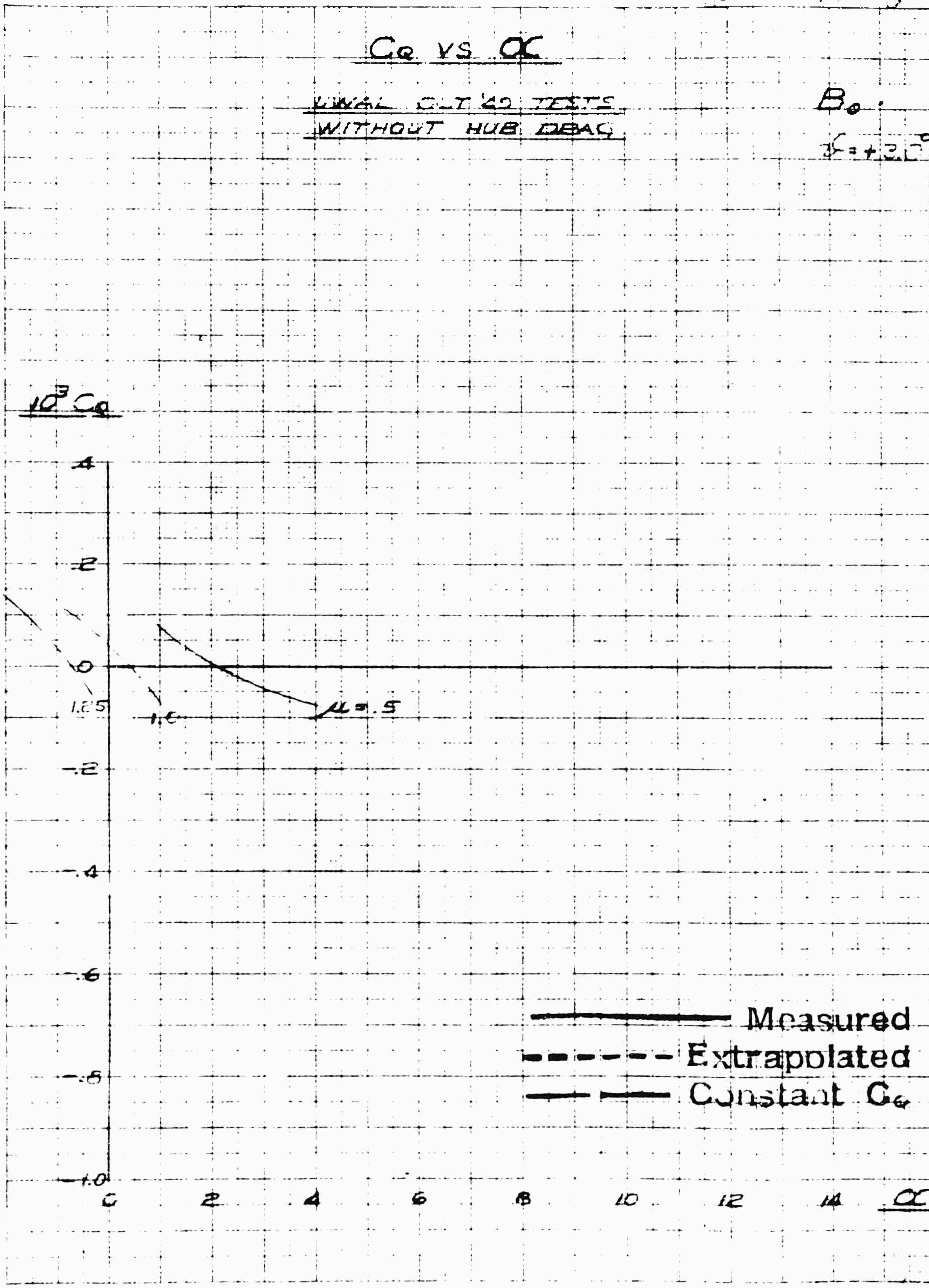
UWAL OCT '49 TESTS
WITHOUT HUB DRAG

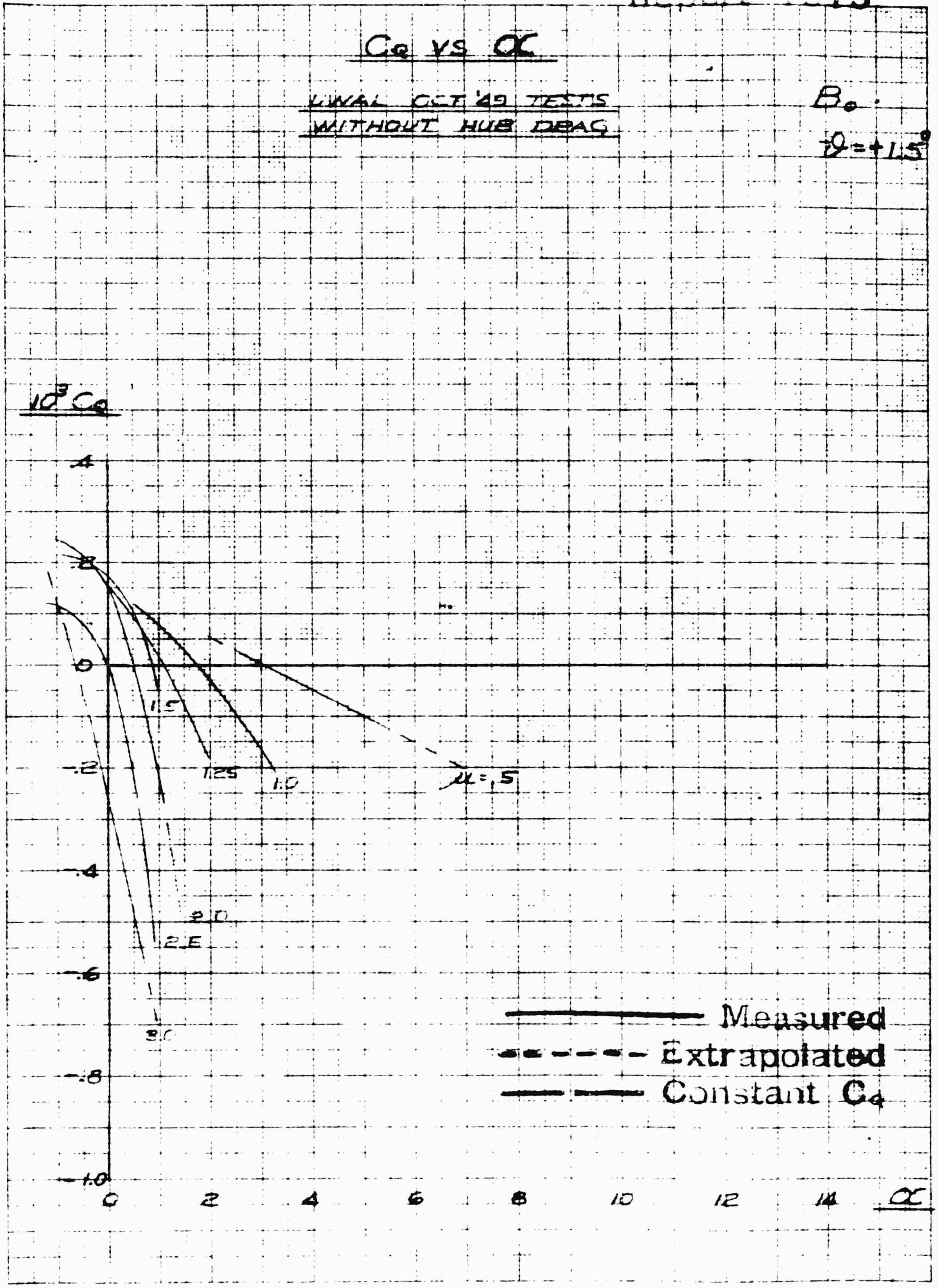
B_e
$\vartheta = -1.5°$



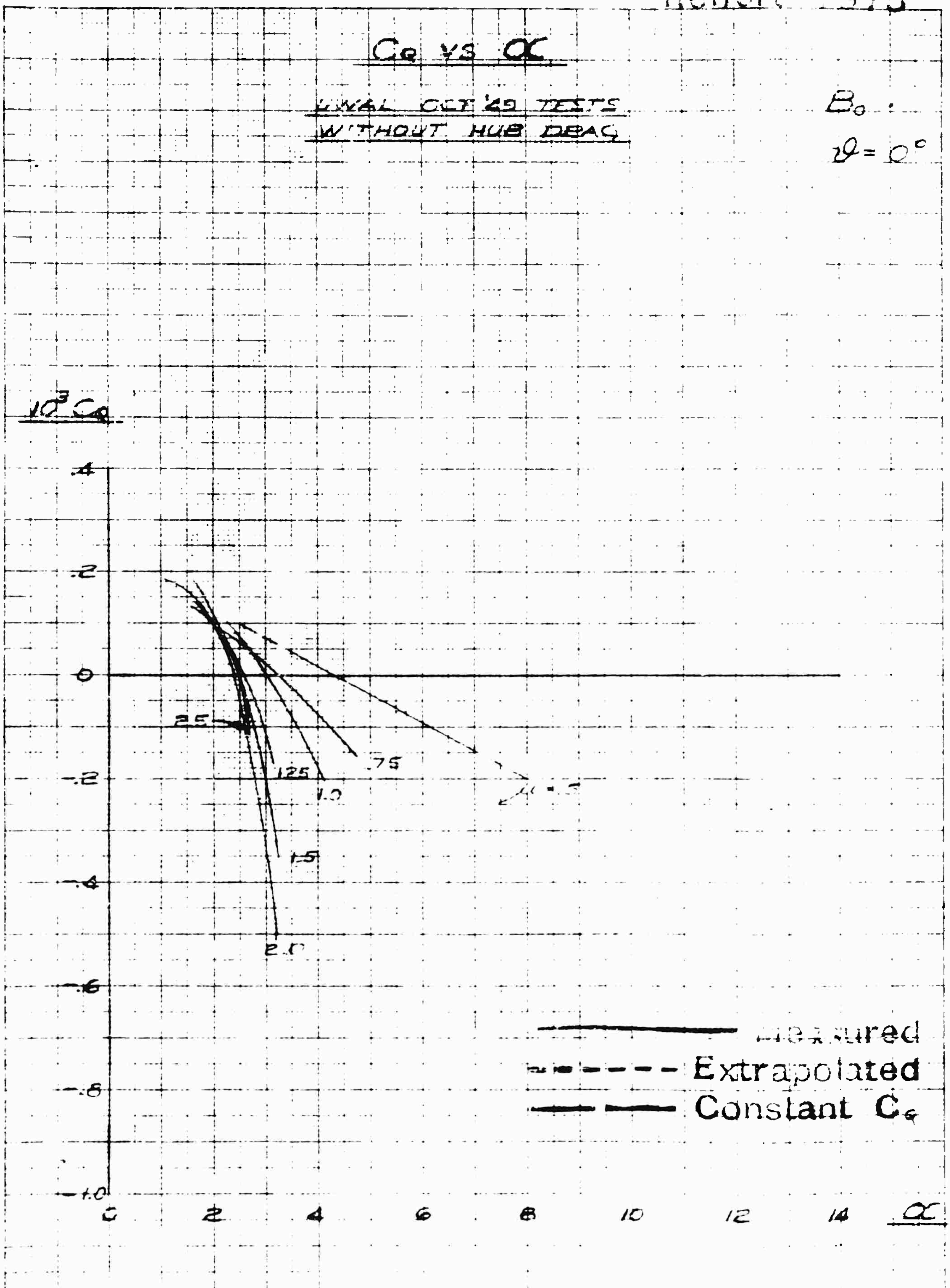

L/D VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
θ = -3.0°
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
μ = 2.0
1.5
1.25
1.0
.75
.5
$C_Q = C$
Measured
Extrapolated
Constant C_Q


L/D VS α
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B₀
ϑ = -4.5°
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
μ = 2.0
1.5
1.25
1.0
.75
.5
C_Q = 0
Measured
Extrapolated
Constant C_Q

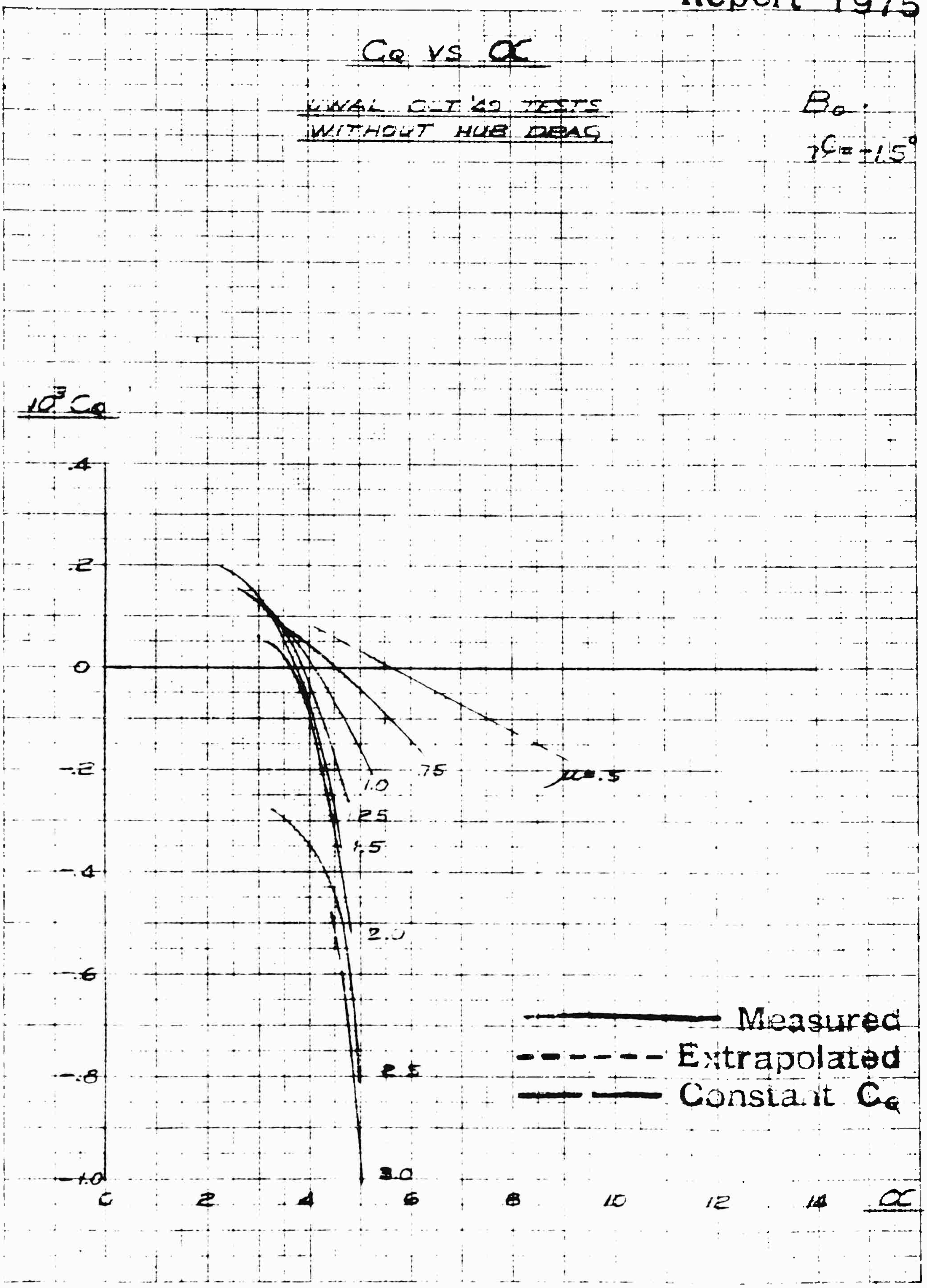

C_Q VS α
UWAL CLT '42 TESTS
WITHOUT HUB DRAG
B_0
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
1.25
1.0
μ = .5
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant C_6

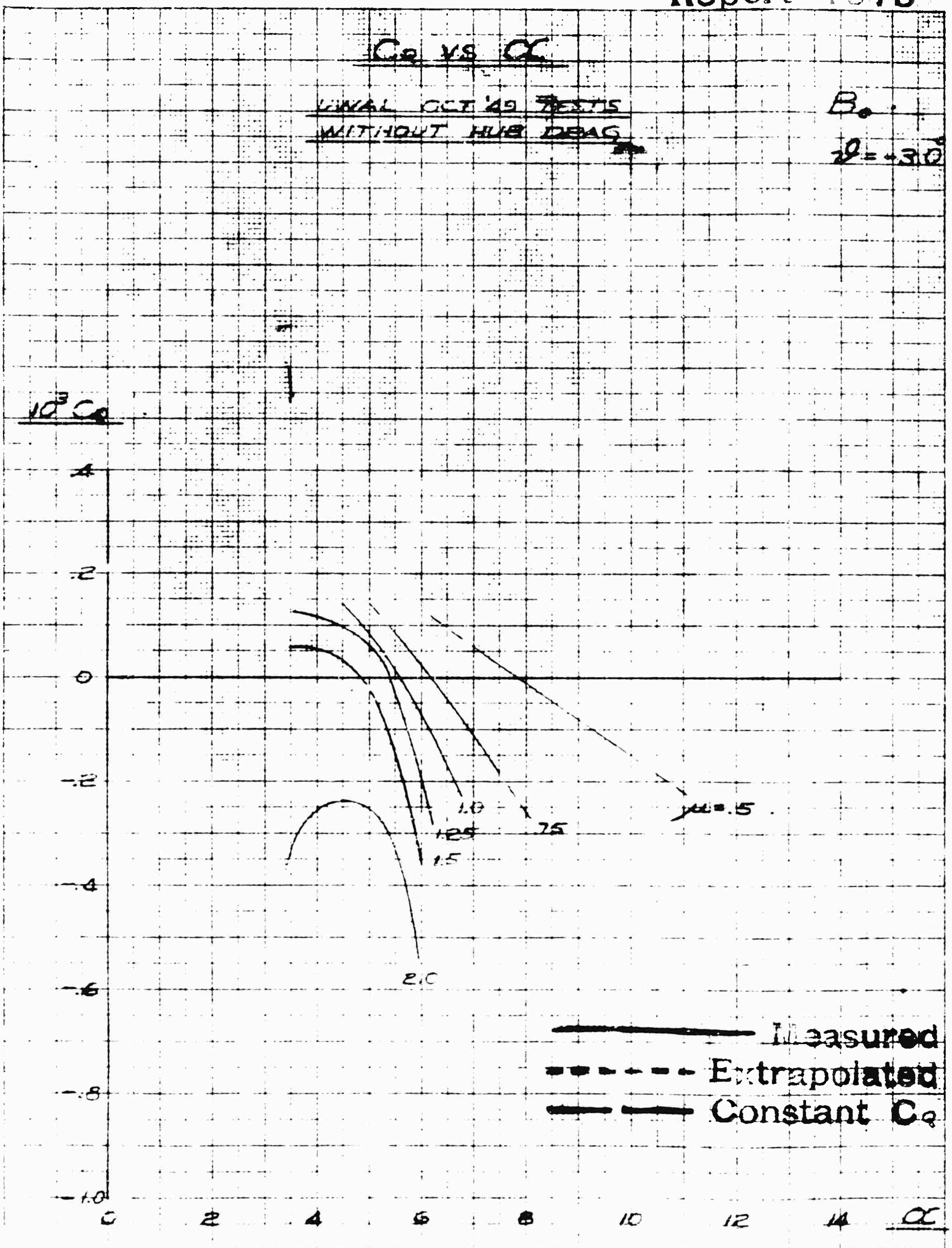


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



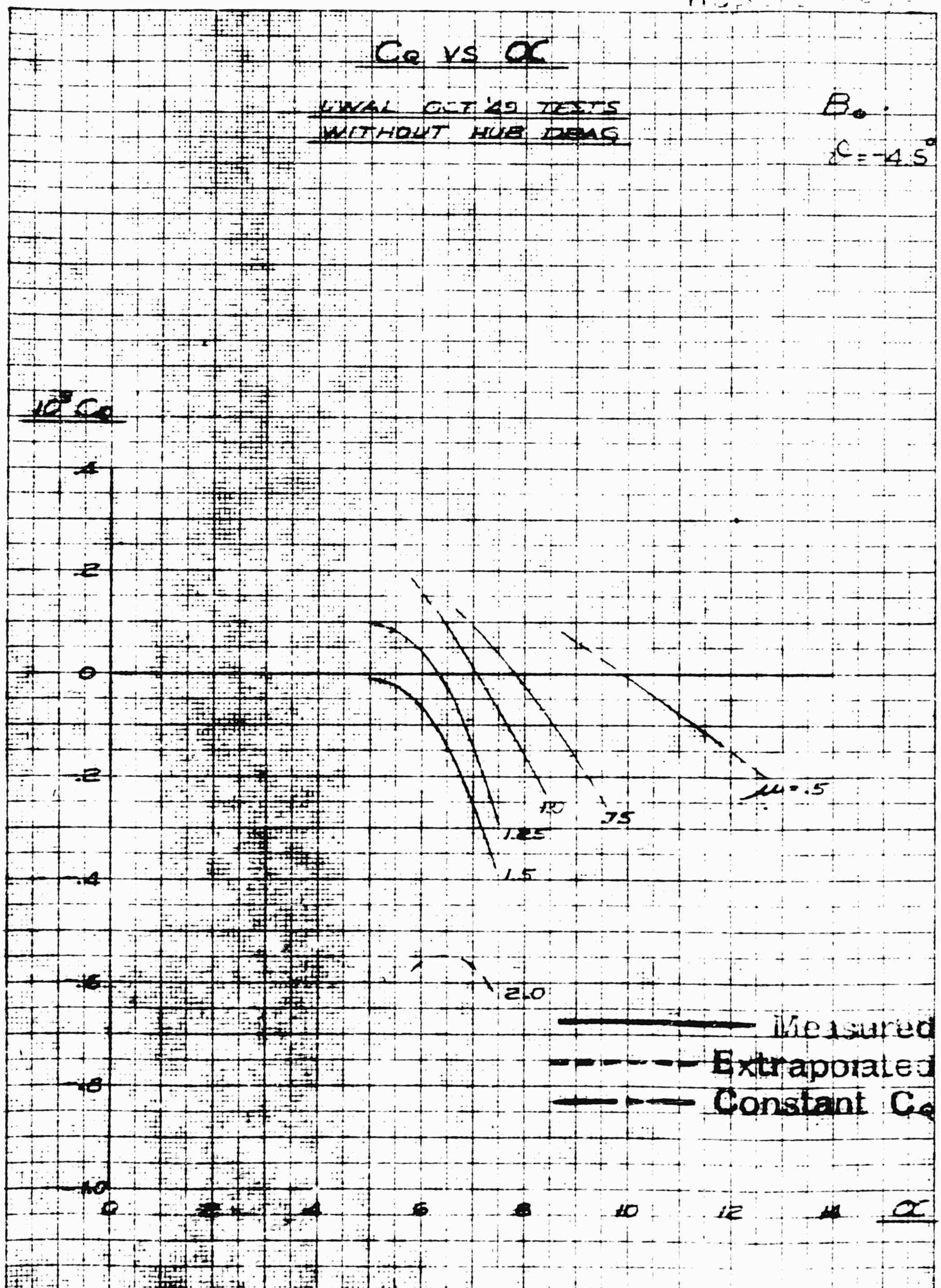
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


C_Q VS α
UWAL OCT '42 TESTS
WITHOUT HUB DRAG
B_0
$\zeta = -1.5°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
$\mu = .5$
.75
1.0
1.25
1.5
2.0
2.5
3.0
Measured
Extrapolated
Constant C_Q



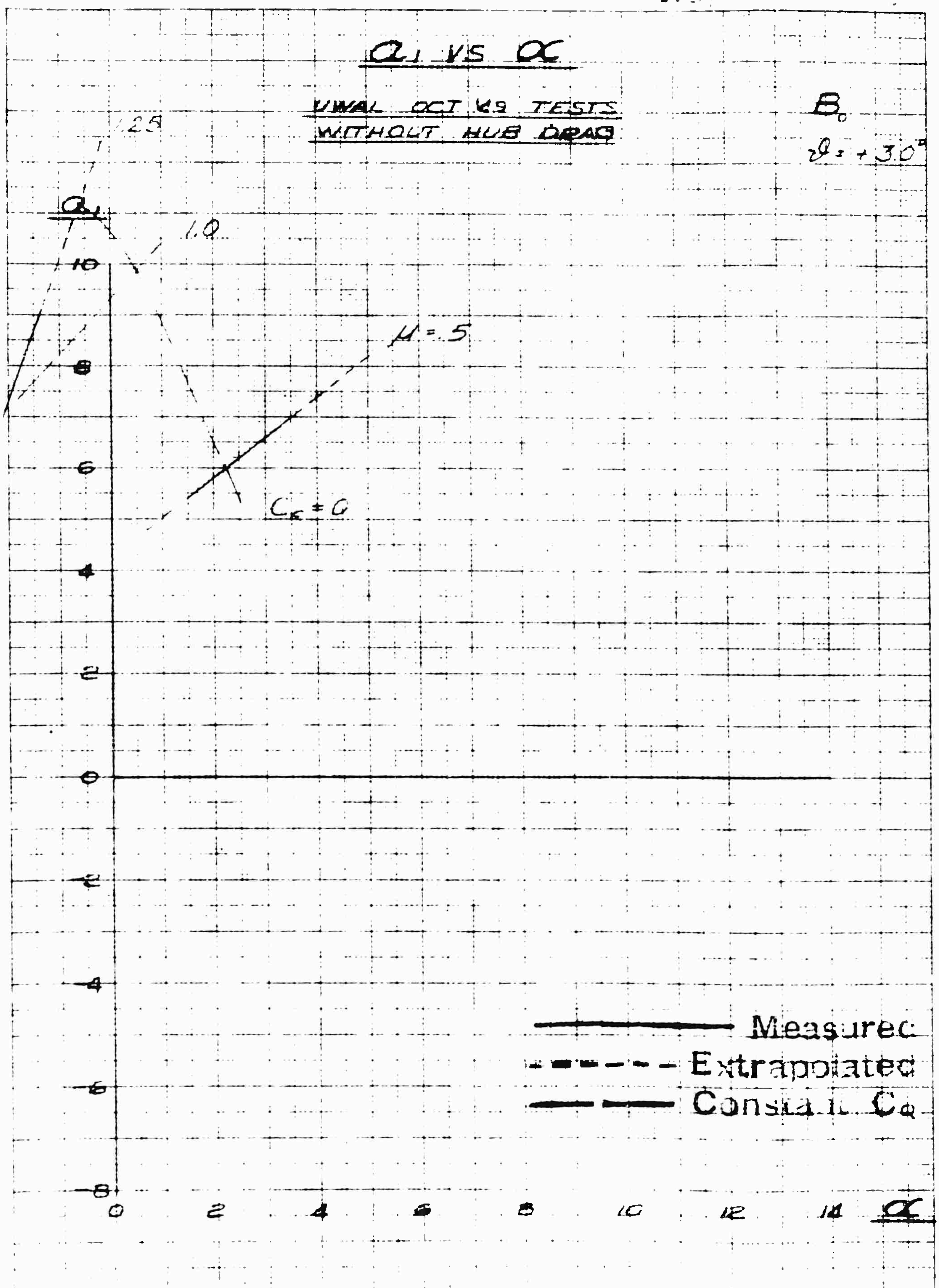
KEUFFEL & ESSER CO.

RBW
12-19-49
72

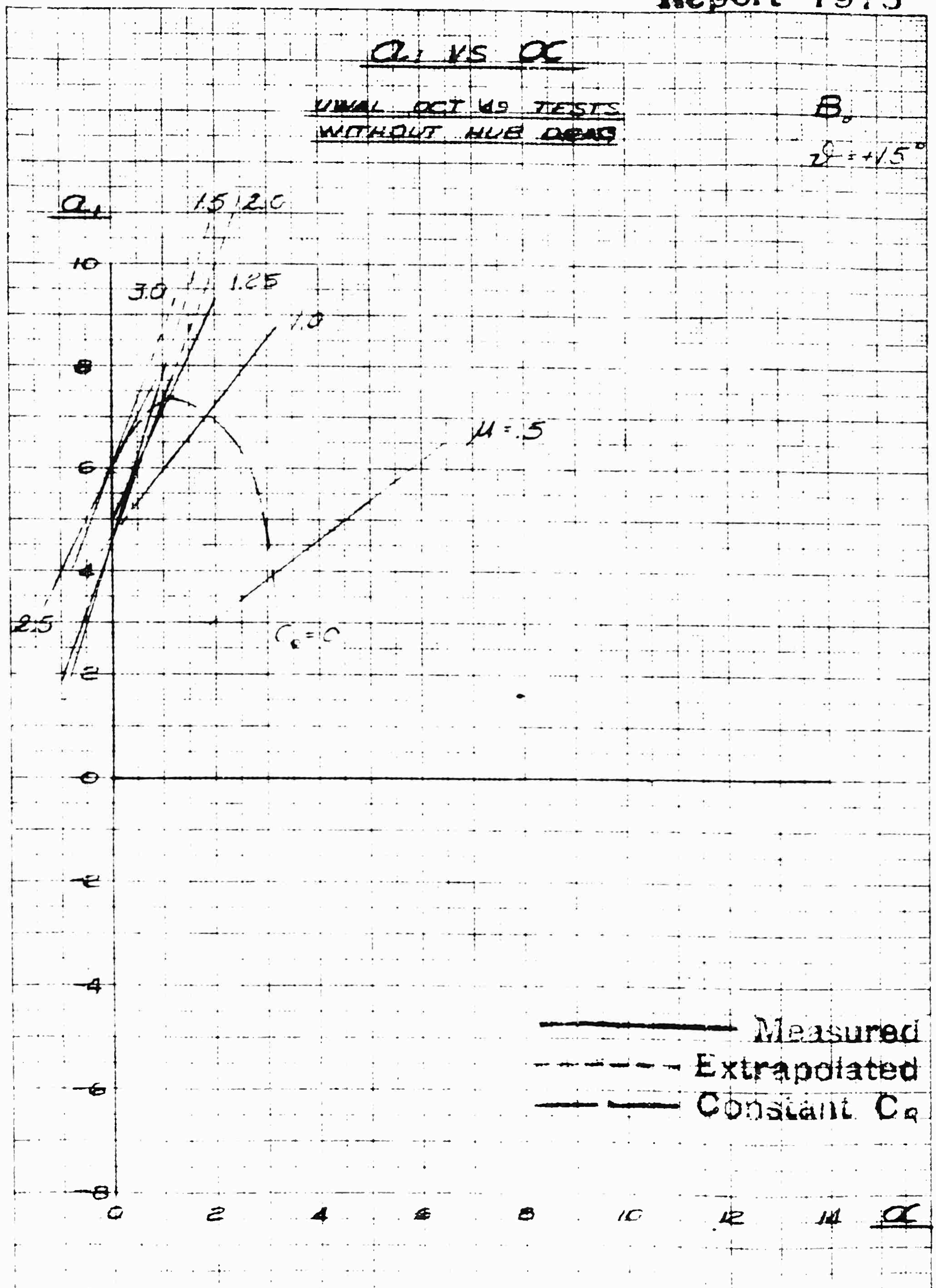


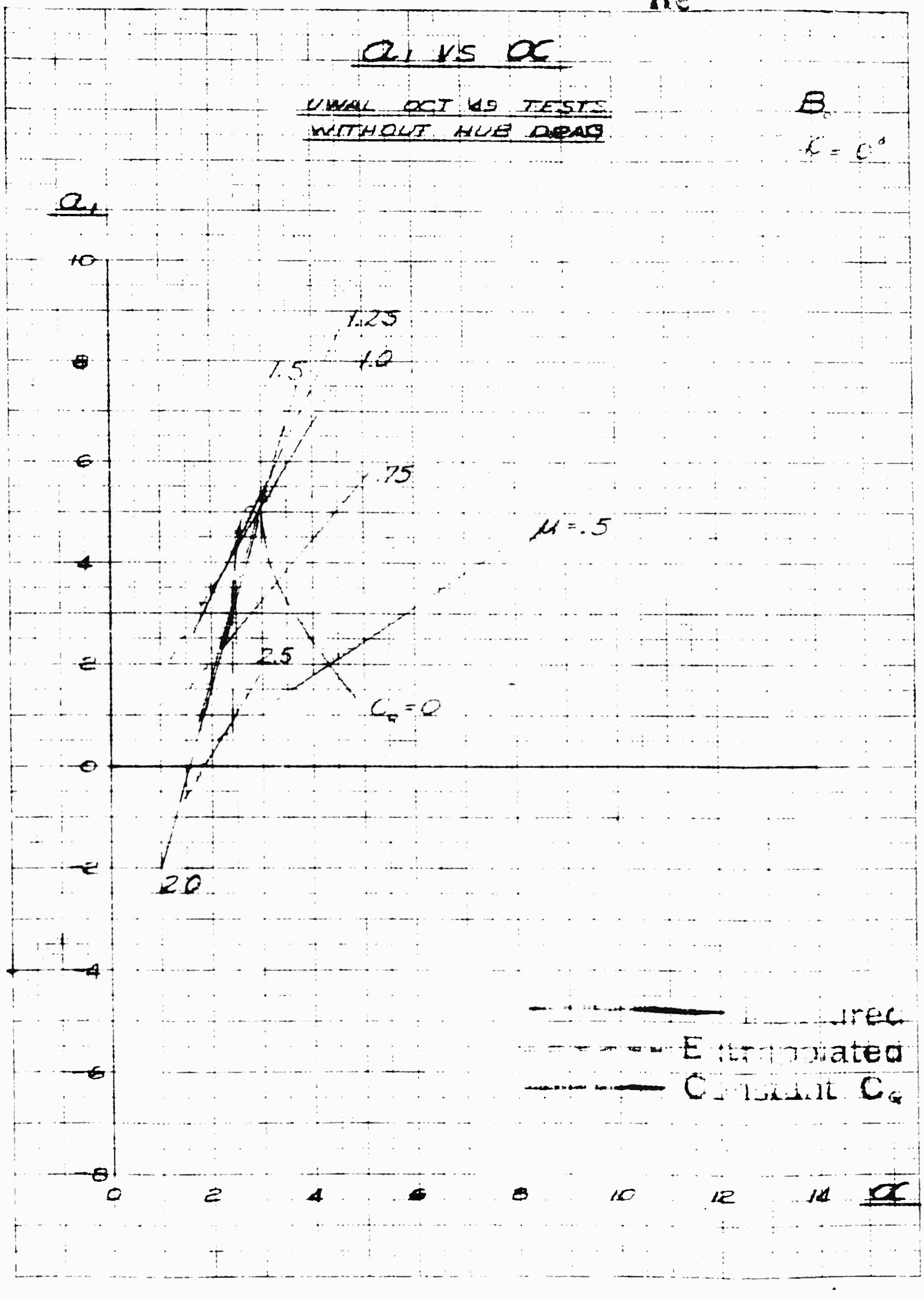
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy.

115

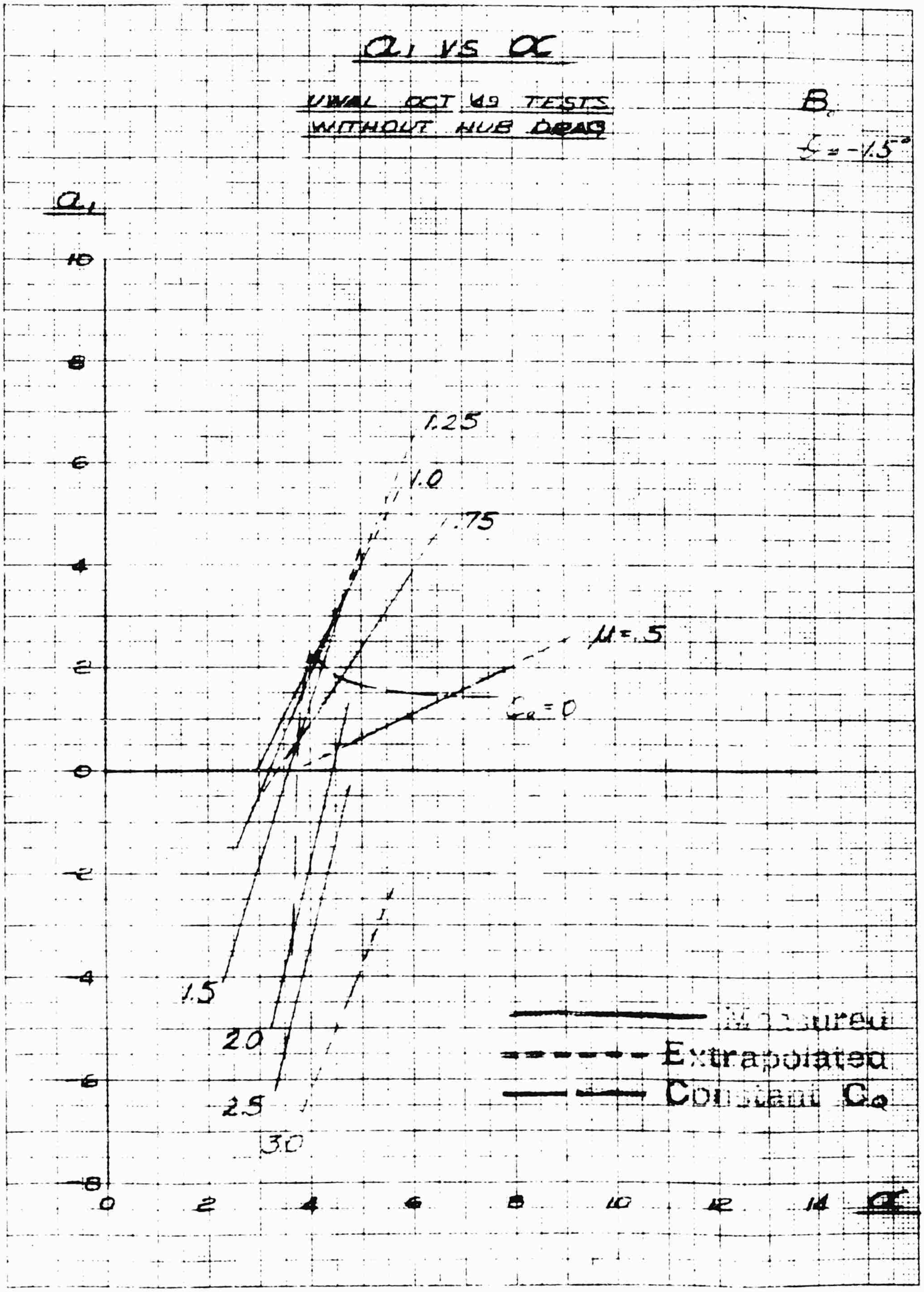


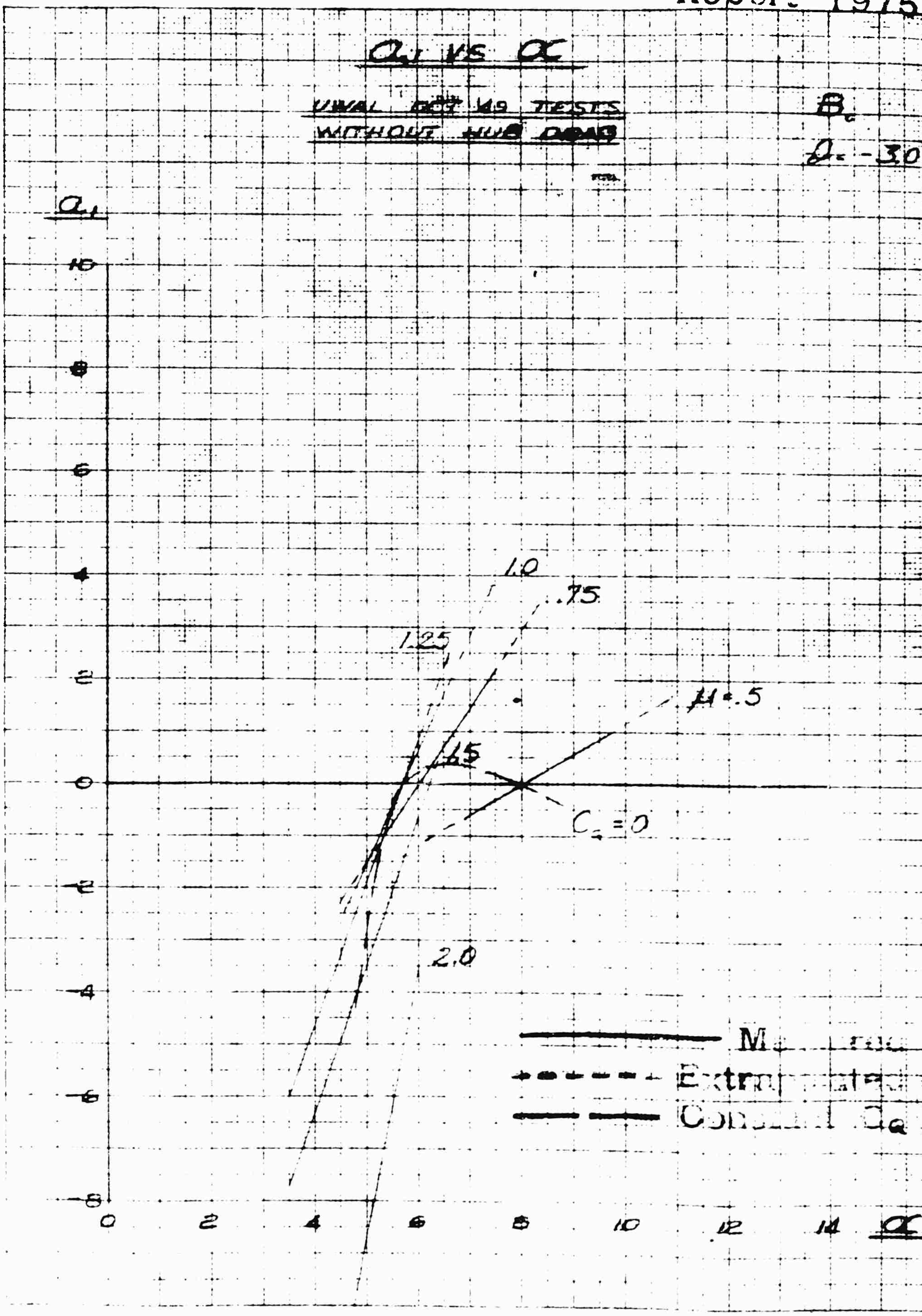
a_1 VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\vartheta = +3.0°$
1.25
1.0
$\mu = .5$
$C_K = 0$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant C_Q

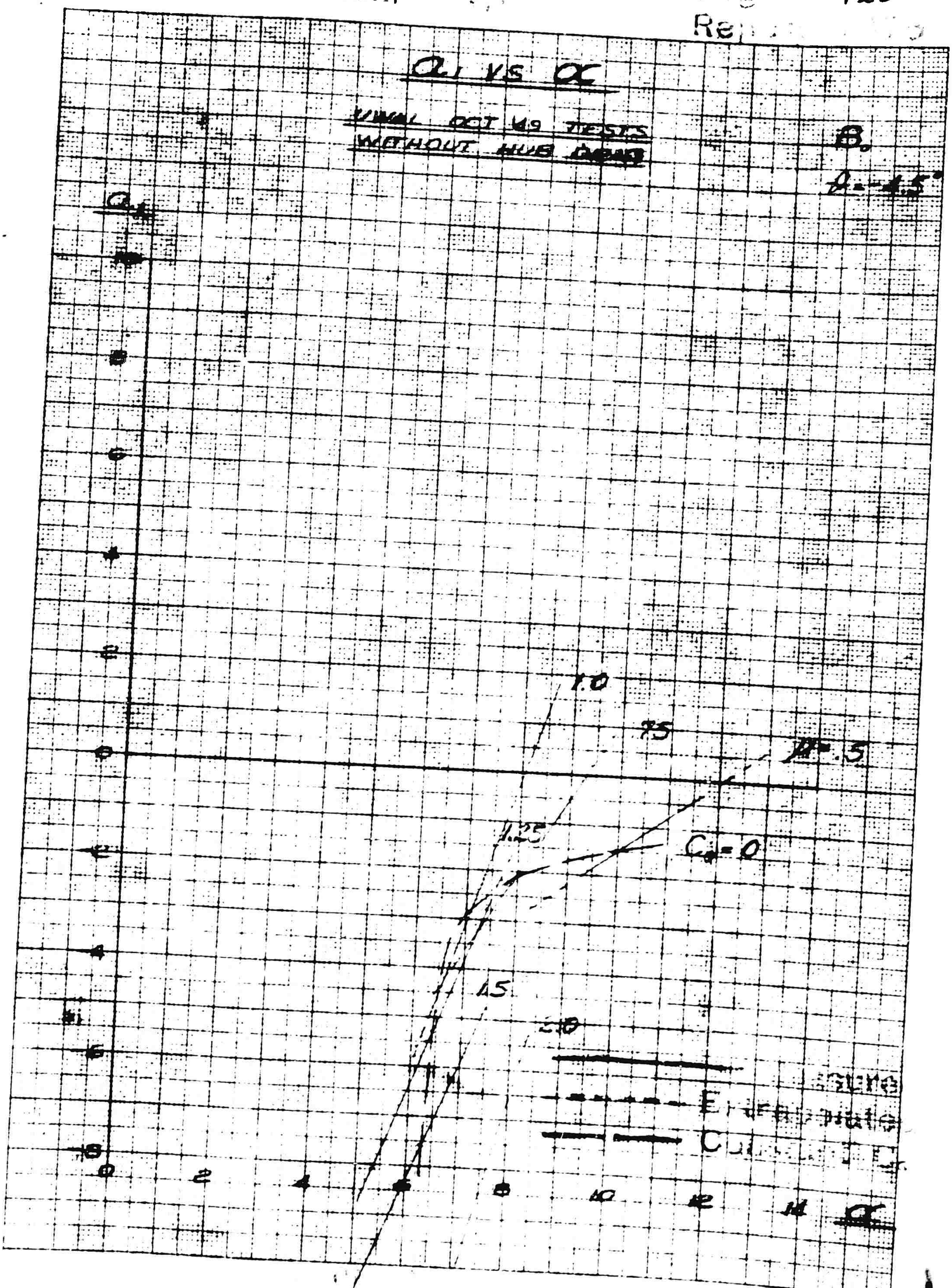

a_1 VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\vartheta = +1.5°$
a_1
1.5
2.0
3.0
1.25
1.0
$\mu = .5$
2.5
$C_Q = 0$
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant C_Q



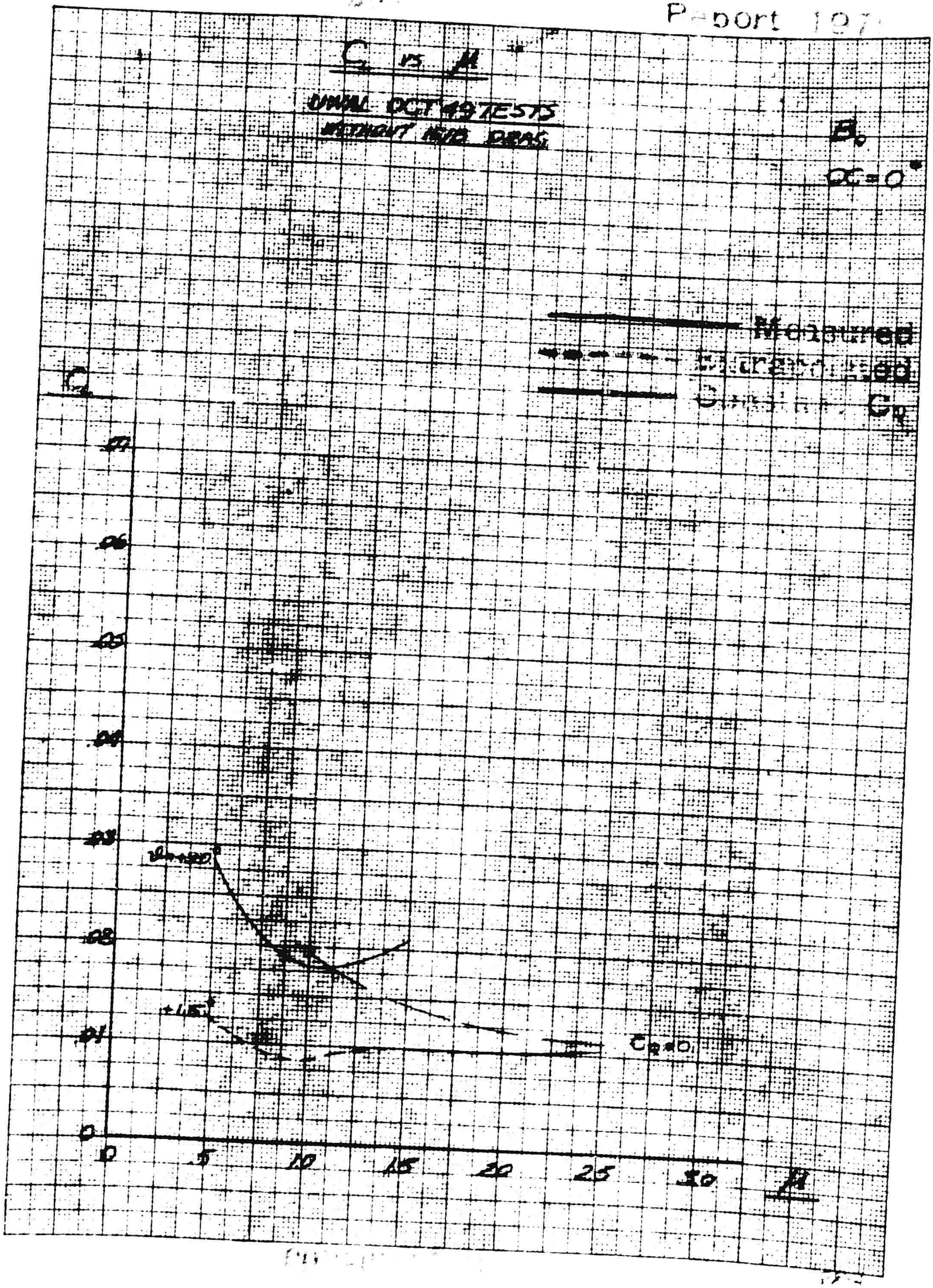
a_1 VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\zeta = 0°$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
1.25
1.0
1.5
.75
$\mu = .5$
2.5
$C_T = 0$
2.0
Extrapolated


a_1 VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\zeta = -1.5°$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
1.25
1.0
.75
$\mu = .5$
$C_Q = 0$
1.5
2.0
2.5
3.0
Measured
Extrapolated
Constant C_Q

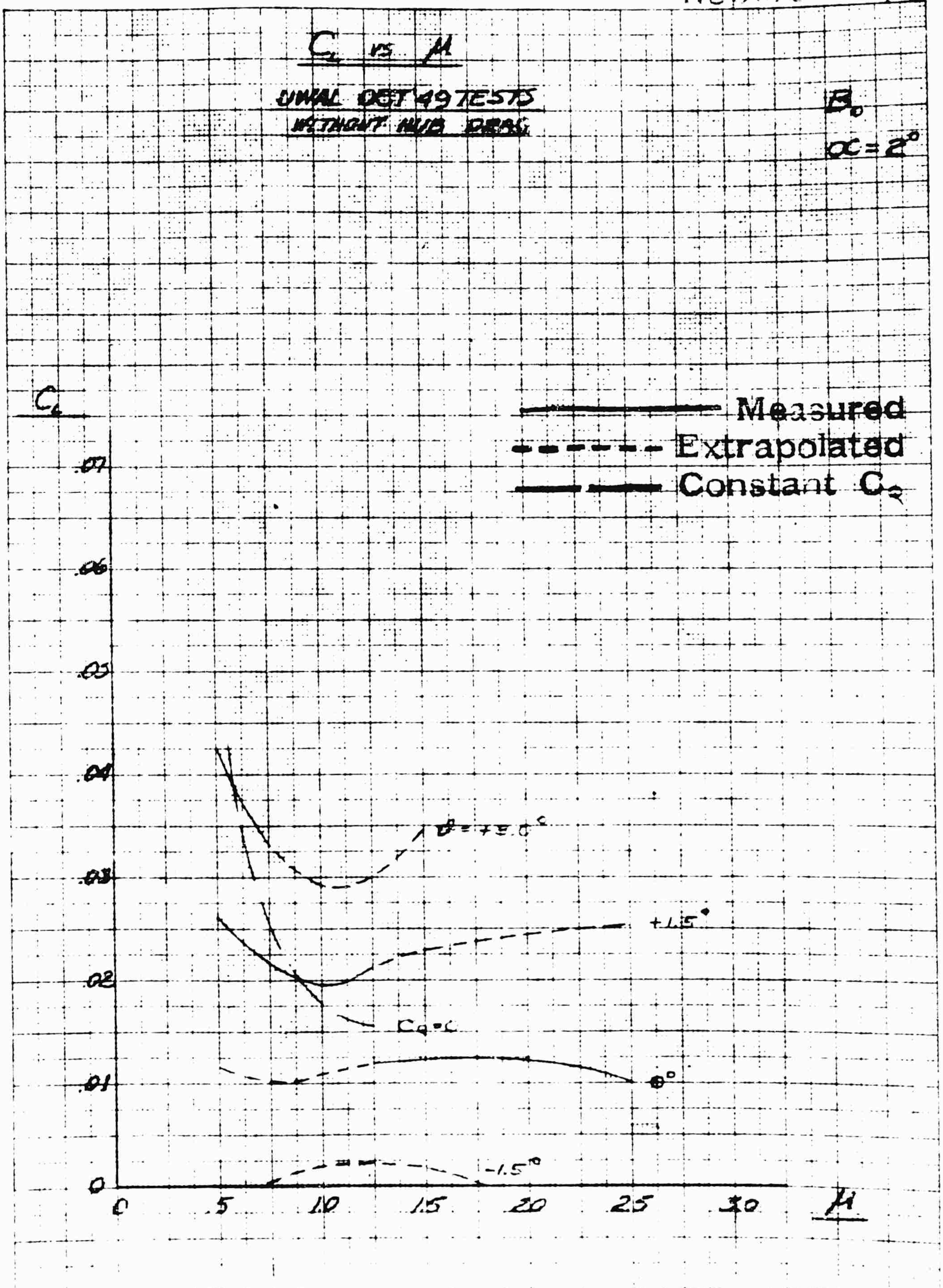

a_1 VS α
UWAL ... 49 TESTS
WITHOUT HUB DRAG
B_c
$\theta = -3.0°$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
α
1.0
.75
1.25
$\mu = .5$
.65
$C_L = 0$
2.0
Measured
Extrapolated
Constant C_Q



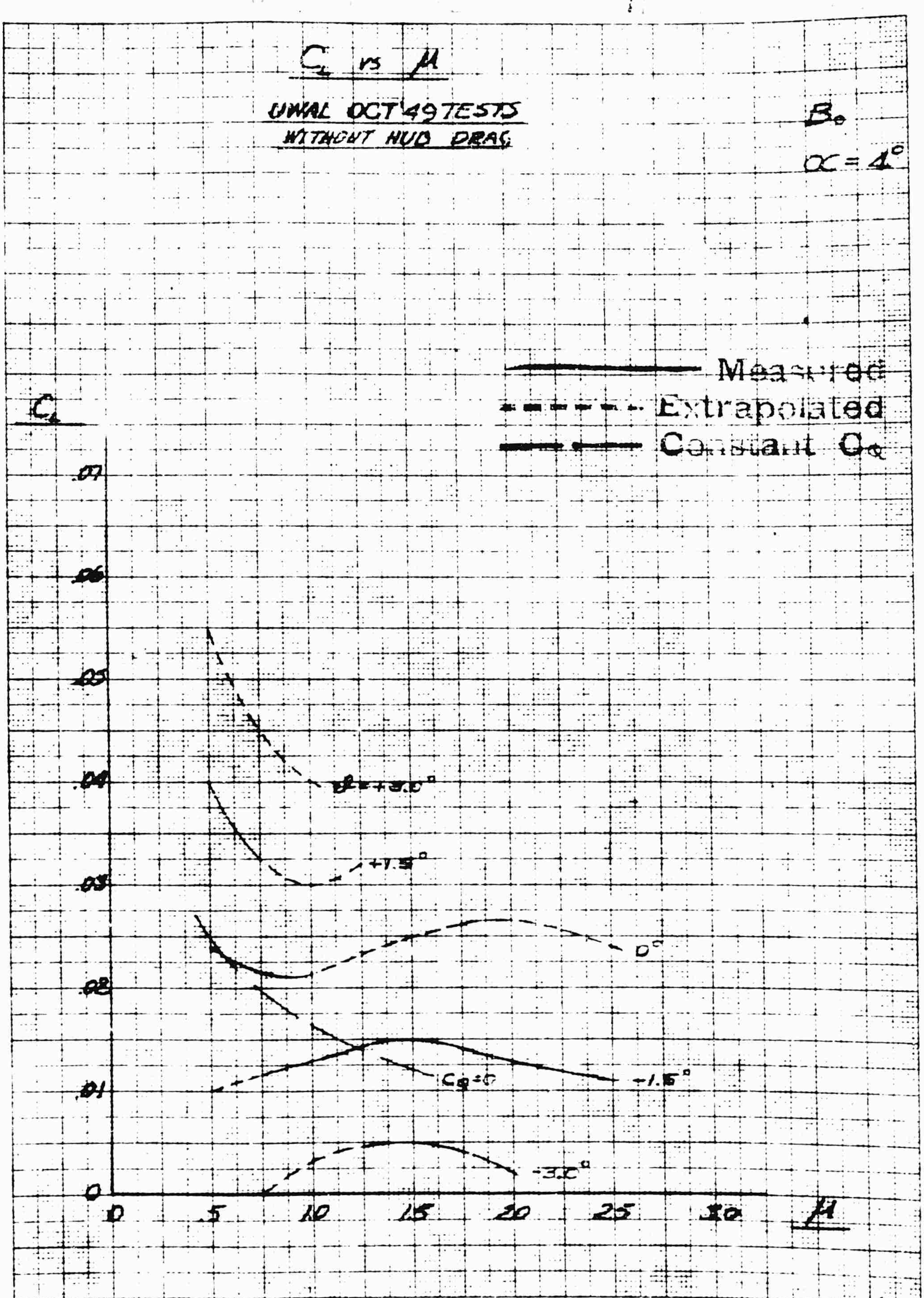
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



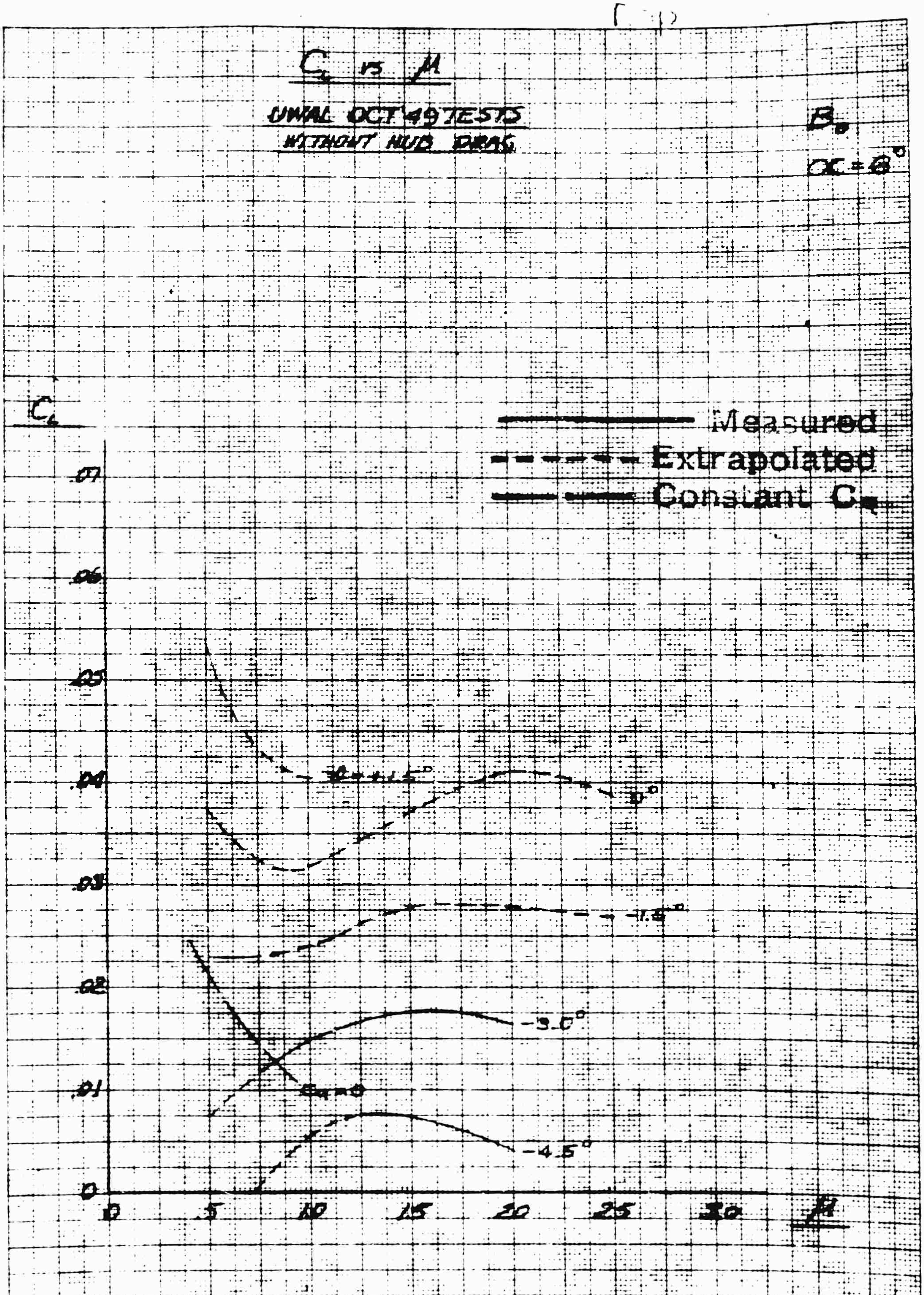
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



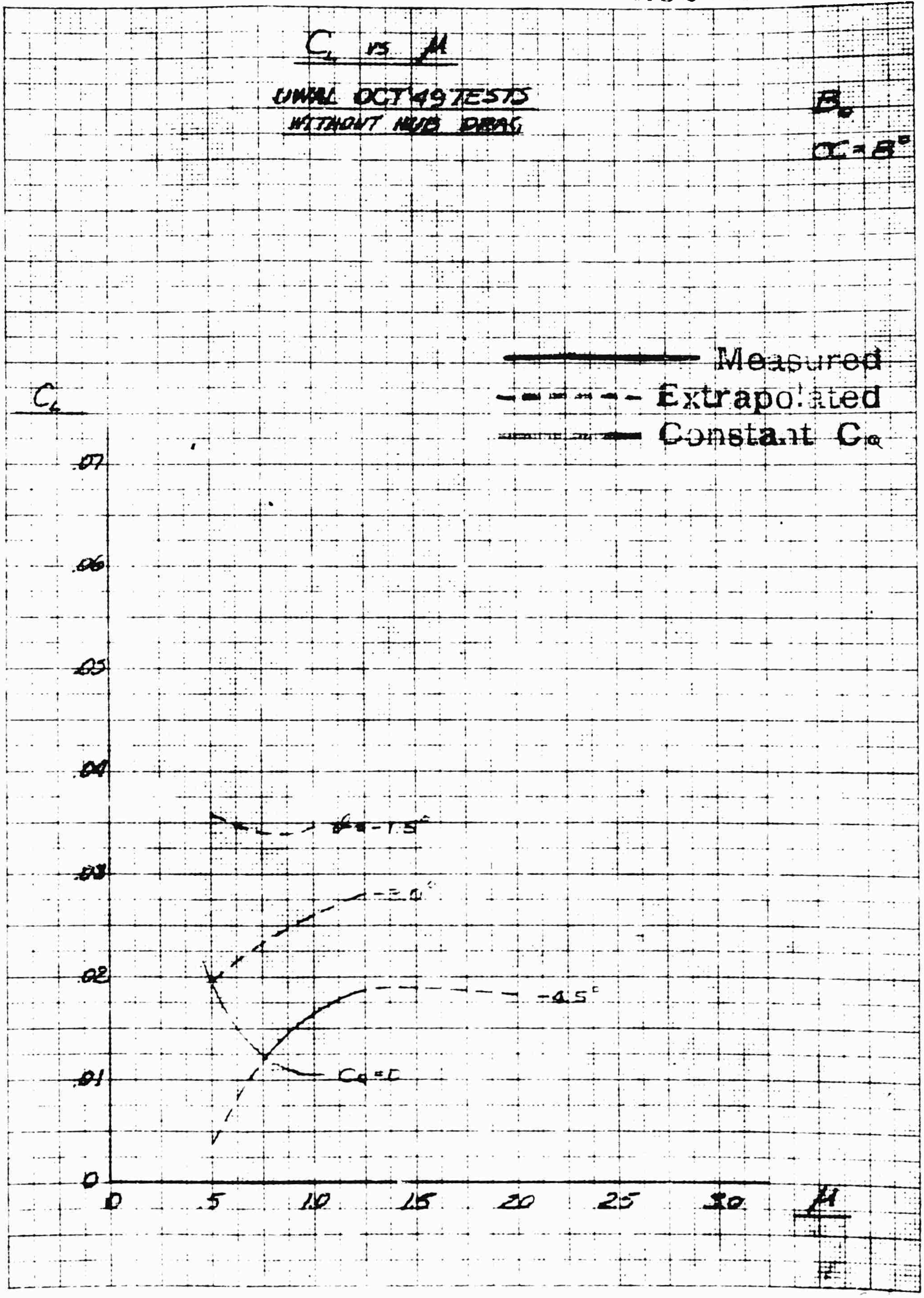
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

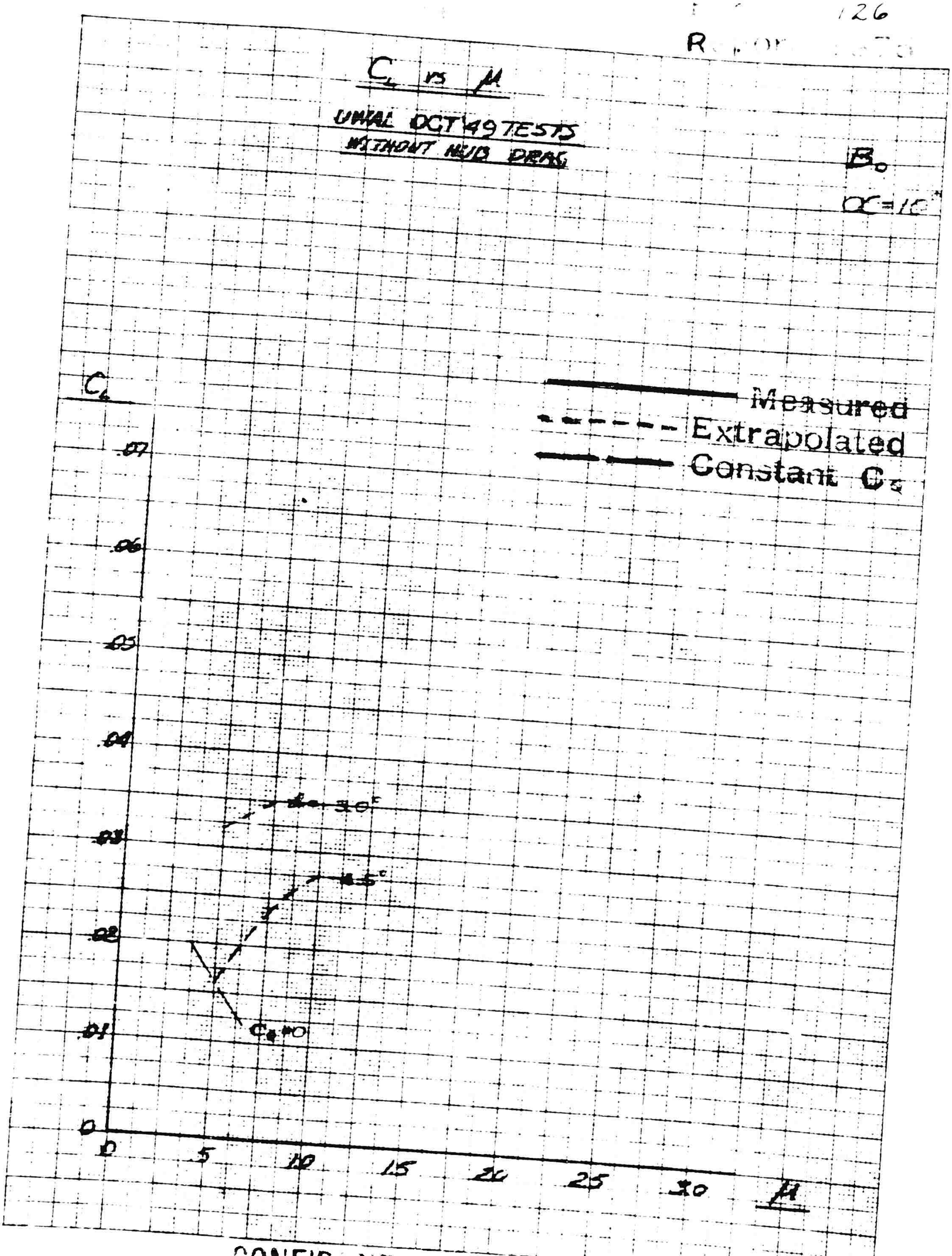


KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



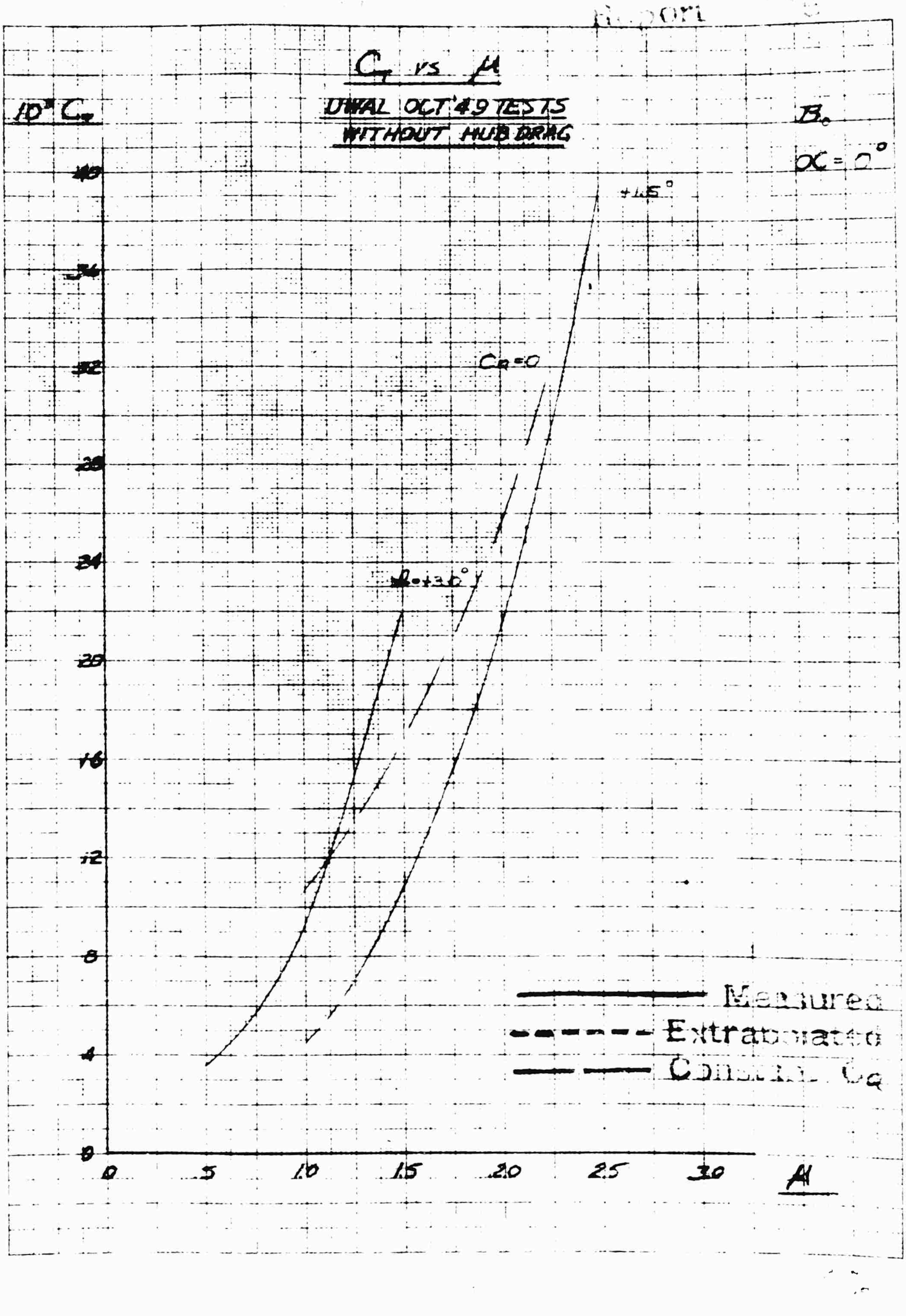
C_L vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B_3
α = 8°
C_L
Measured
Extrapolated
Constant C_q
.07
.06
.05
.04
.03
.02
.01
0
0
.5
.10
.15
.20
.25
.30
μ
θ = +1.5°
0°
-1.5°
-3.0°
-4.5°
C_q = 0


C_L vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_c
$\alpha = 8°$
Measured
Extrapolated
Constant C_Q
C_L
.07
.06
.05
.04
.03
.02
.01
0
$\theta = -1.5°$
$-3.0°$
$-4.5°$
$C_Q = 0$
0
.5
1.0
1.5
2.0
2.5
3.0
μ

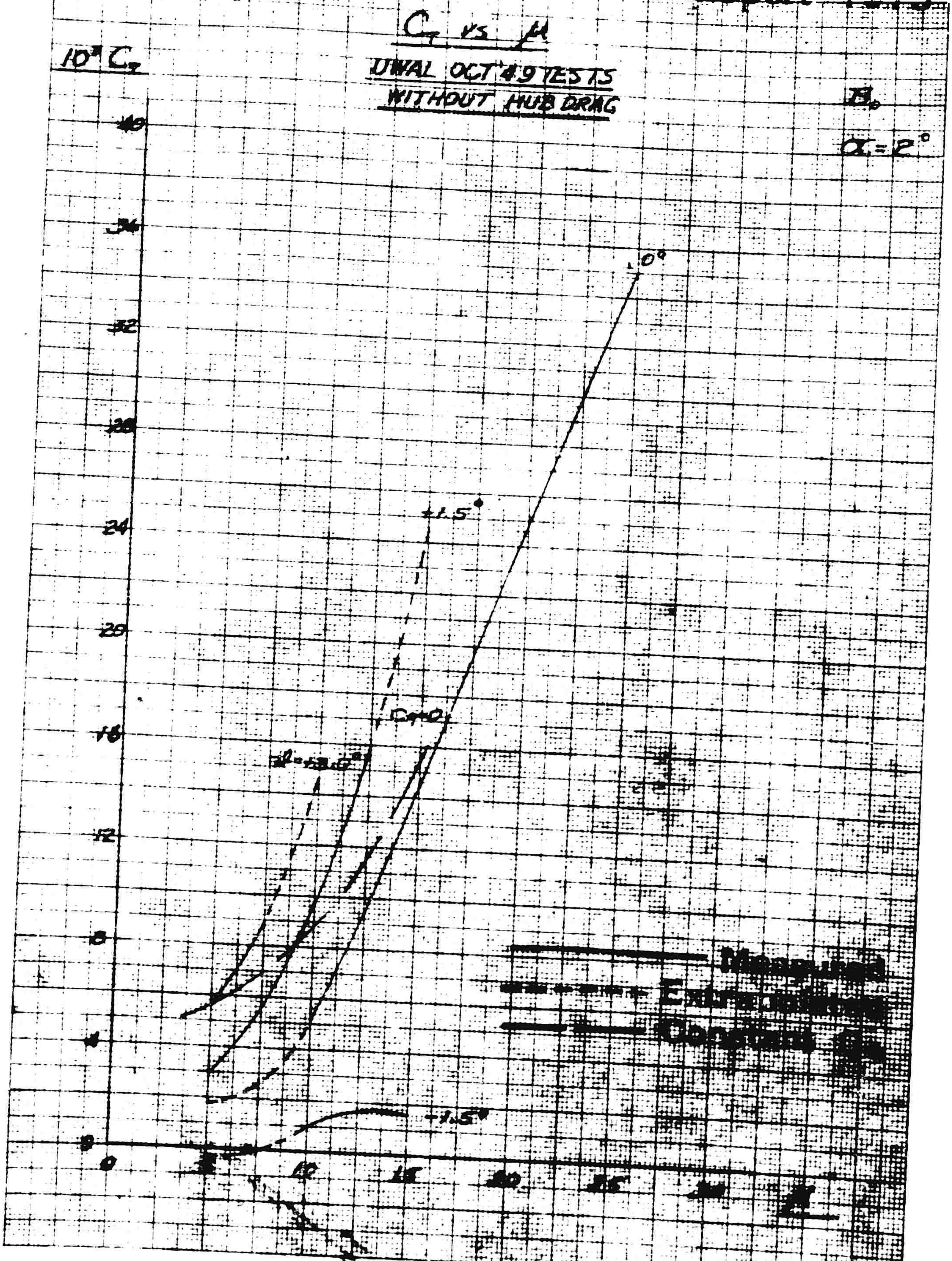


No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy. KEUFFEL & ESSER CO.

CONFIDENTIAL

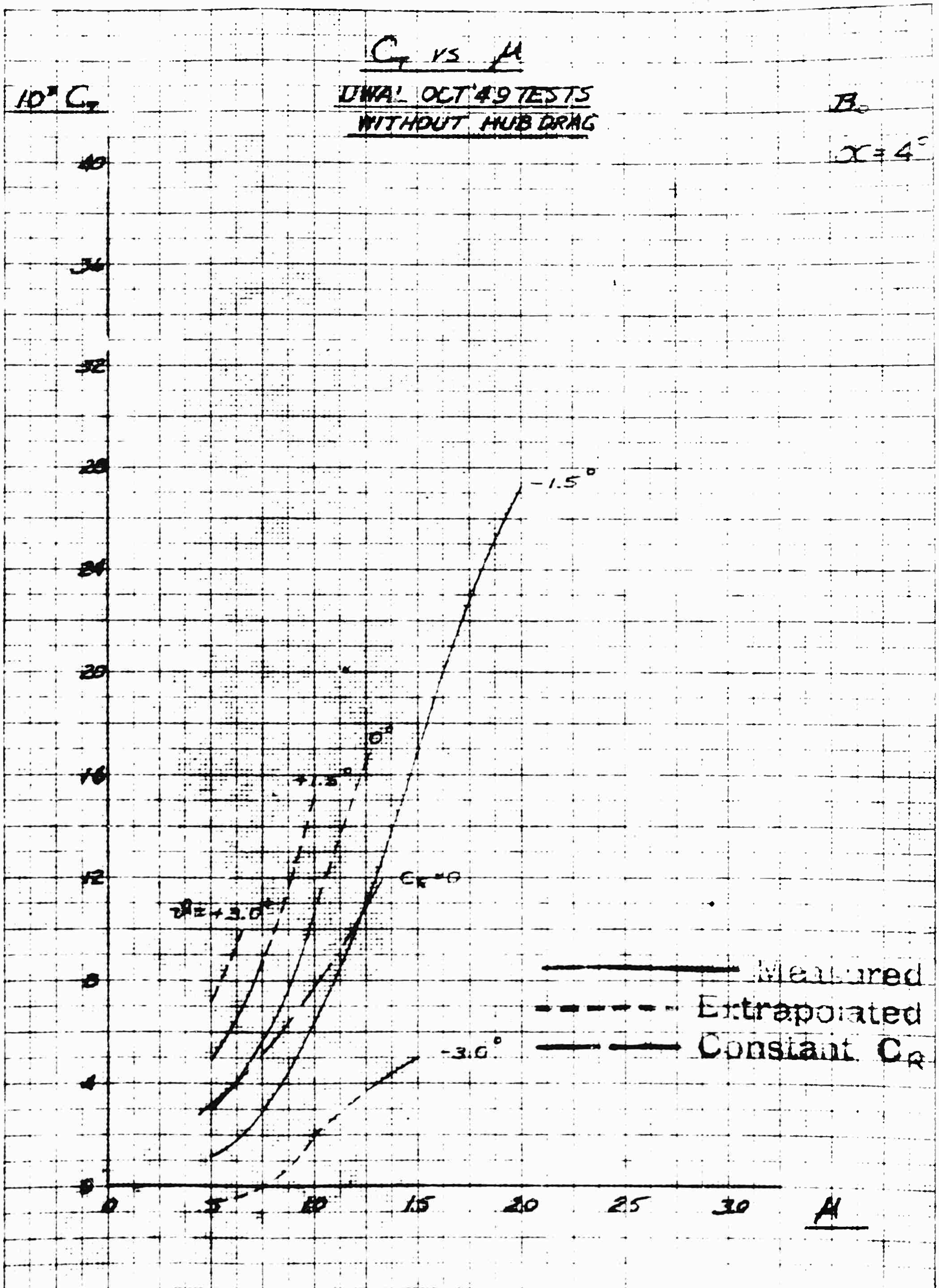


C_T vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^3 C_T$
B_o
$\alpha = 0°$
+15°
$C_Q = 0$
+13.0°
Measured
Extrapolated
Constant C_Q
0
4
8
12
16
20
24
28
32
36
40
0
.5
1.0
1.5
2.0
2.5
3.0
μ

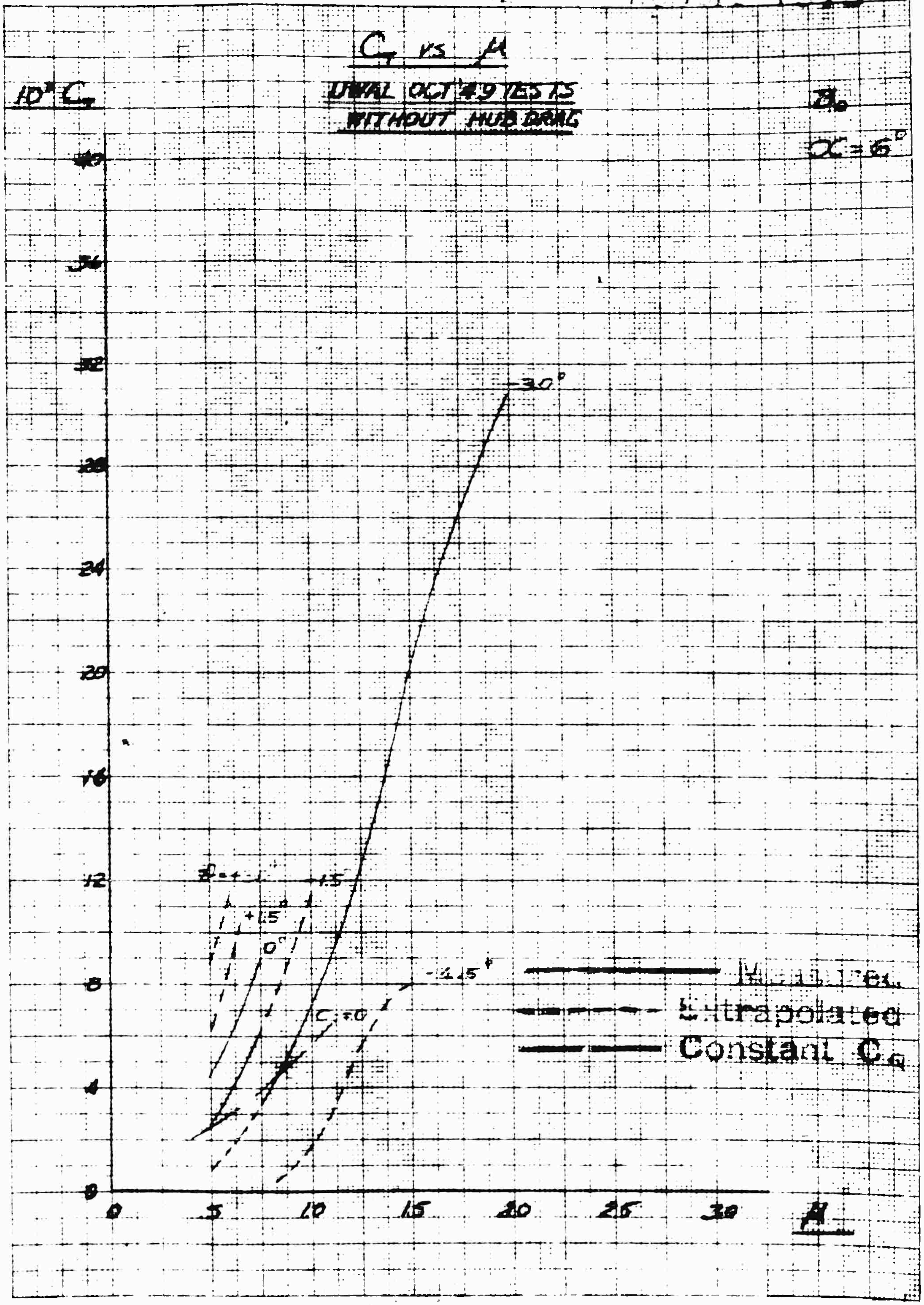


CONFIDENTIAL

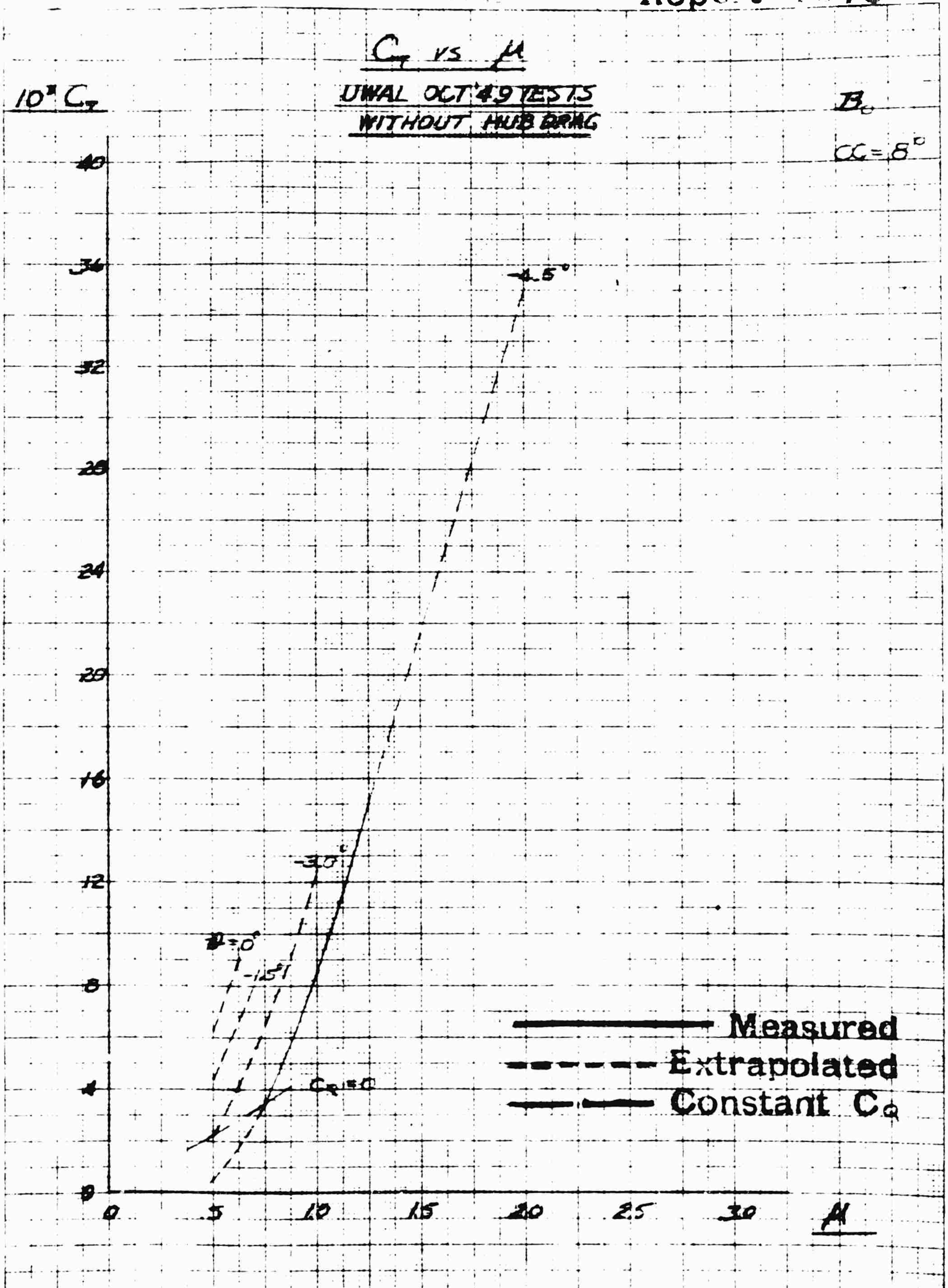
12-14-49

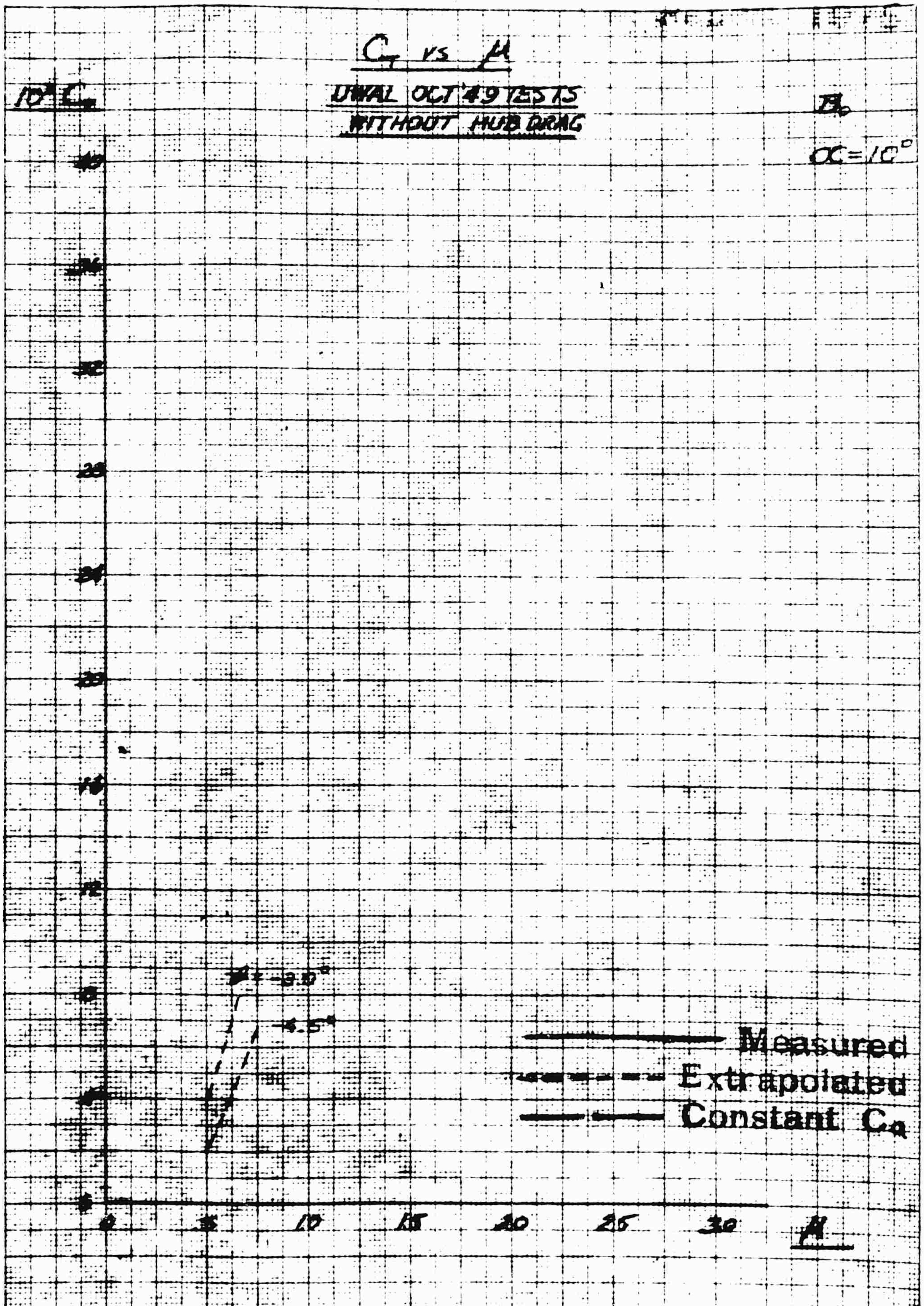


CONFIDENTIAL

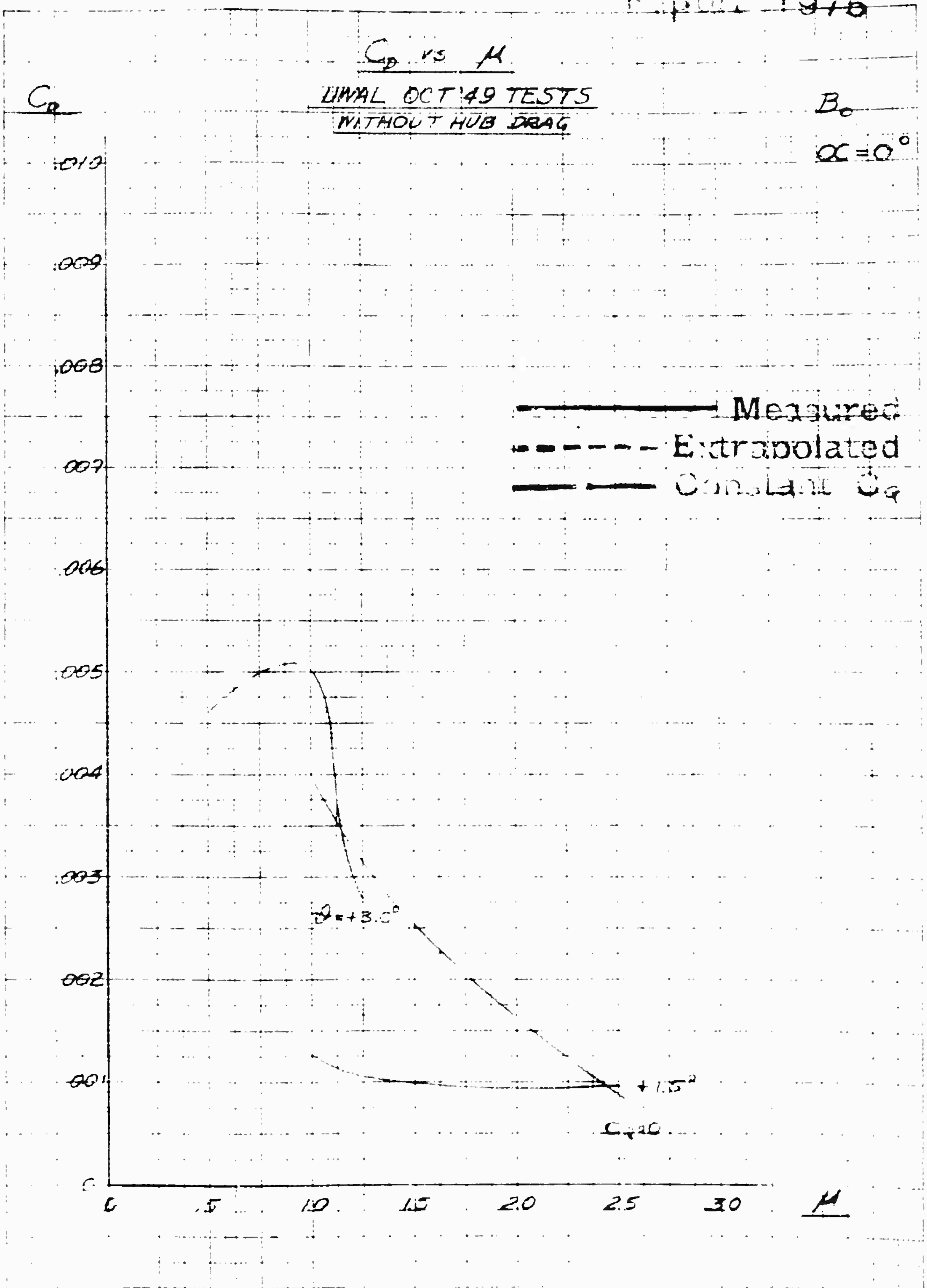


KEUFFEL & ESSER CO.
No. 359-11 Millimeters


C_T vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^3 C_T$
B_0
$\alpha = 8°$
40
36
32
28
24
20
16
12
8
4
0
0
.5
1.0
1.5
2.0
2.5
3.0
μ
4.5°
3.0°
$B_1 = 0°$
1.5°
$C_Q = 0$
Measured
Extrapolated
Constant C_Q

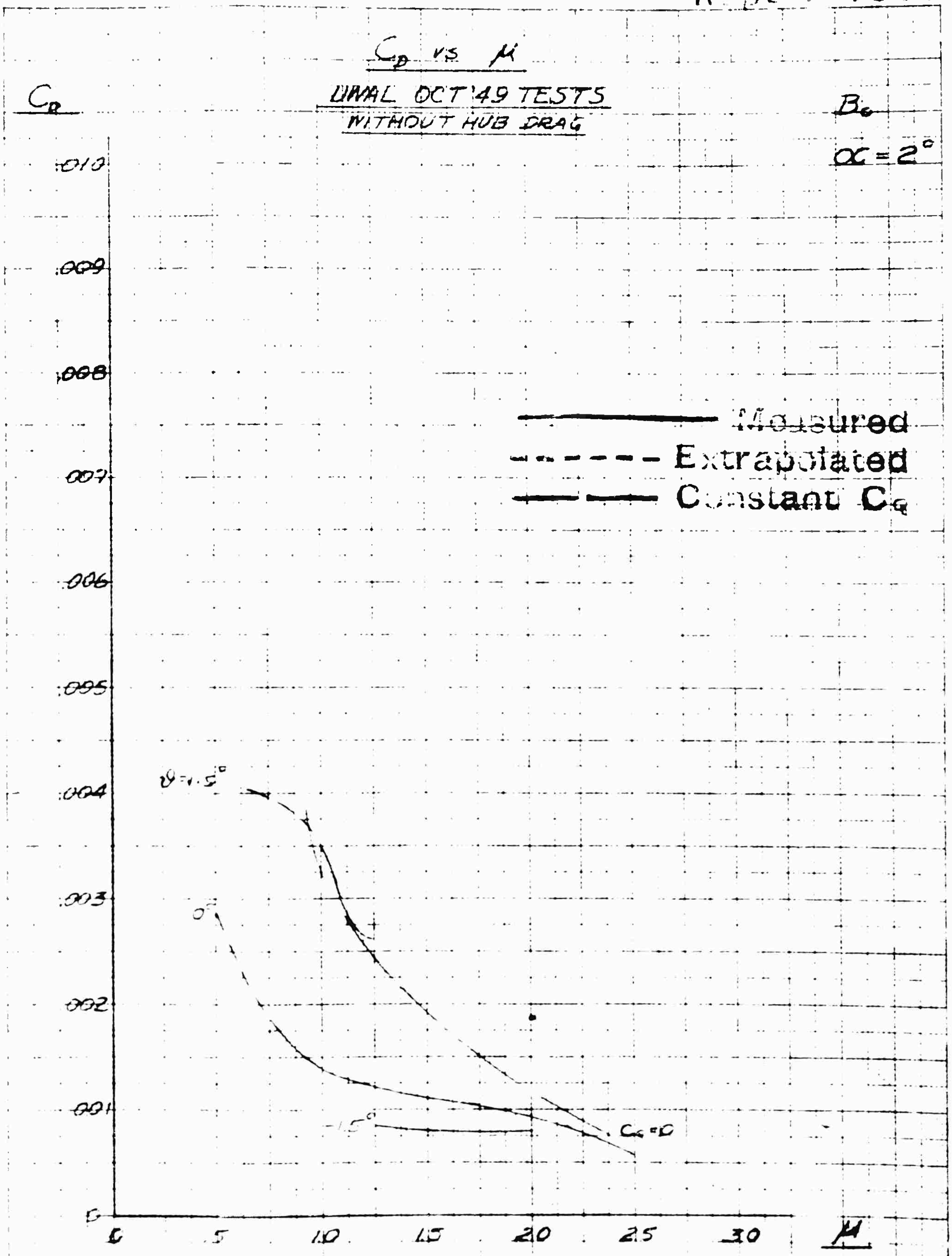


KEUFFEL & ESSER CO
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy



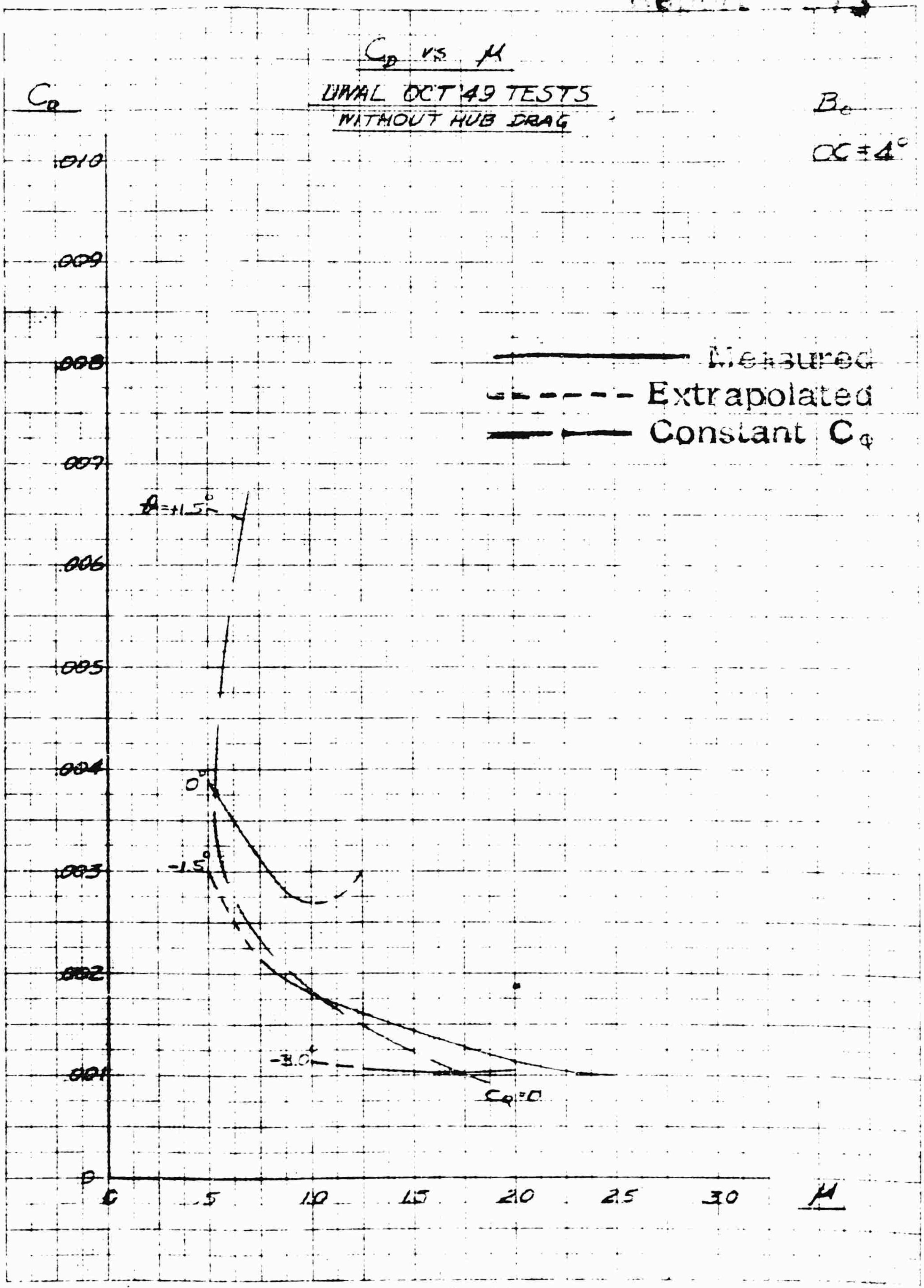
C_D vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
C_D
B_c
$\alpha = 0°$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_Q
$\theta = +3.0°$
$+1.5°$
$C_Q = 0$

CON...



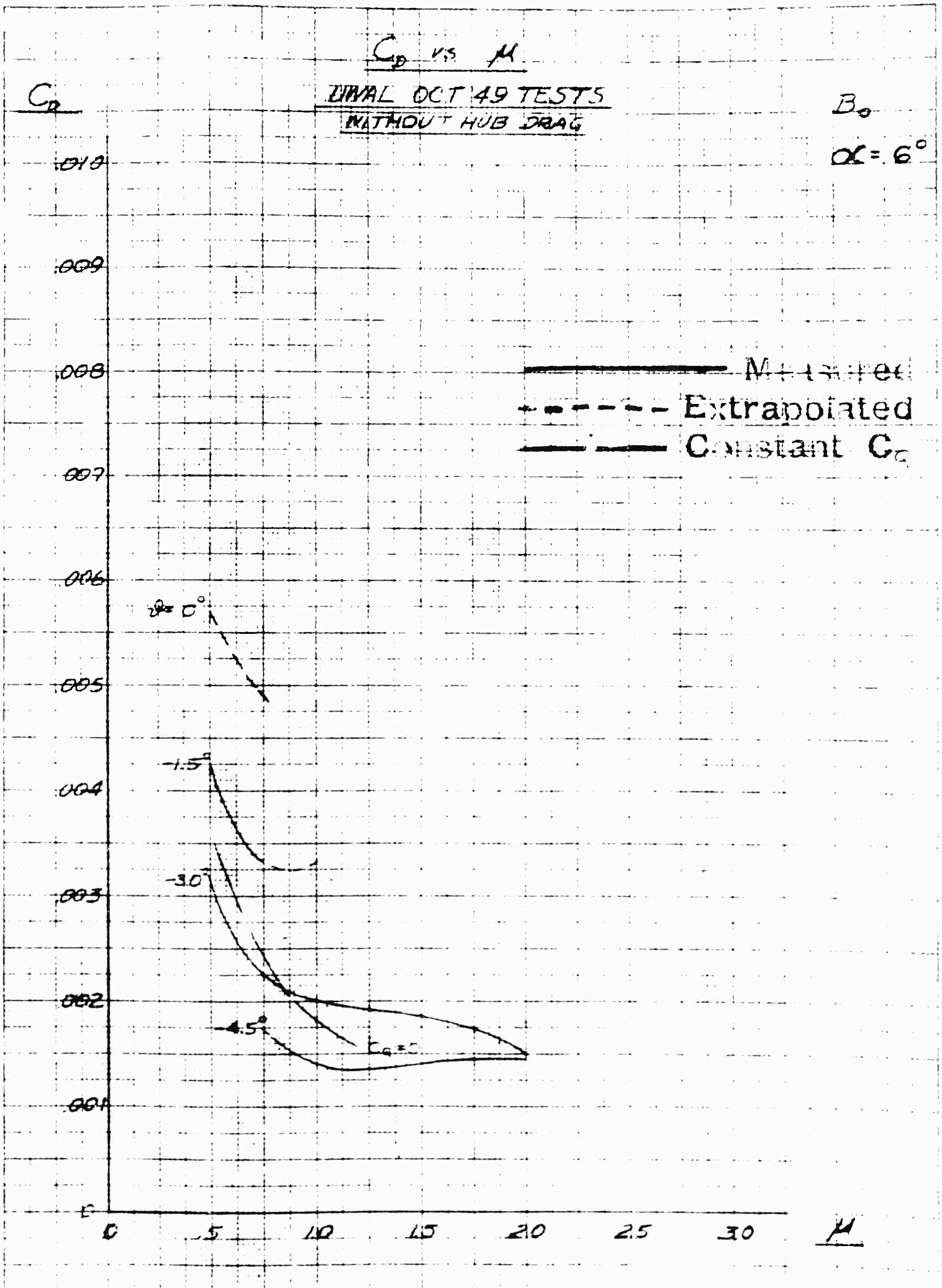
CONFIDENTIAL

JCE
12-14-49



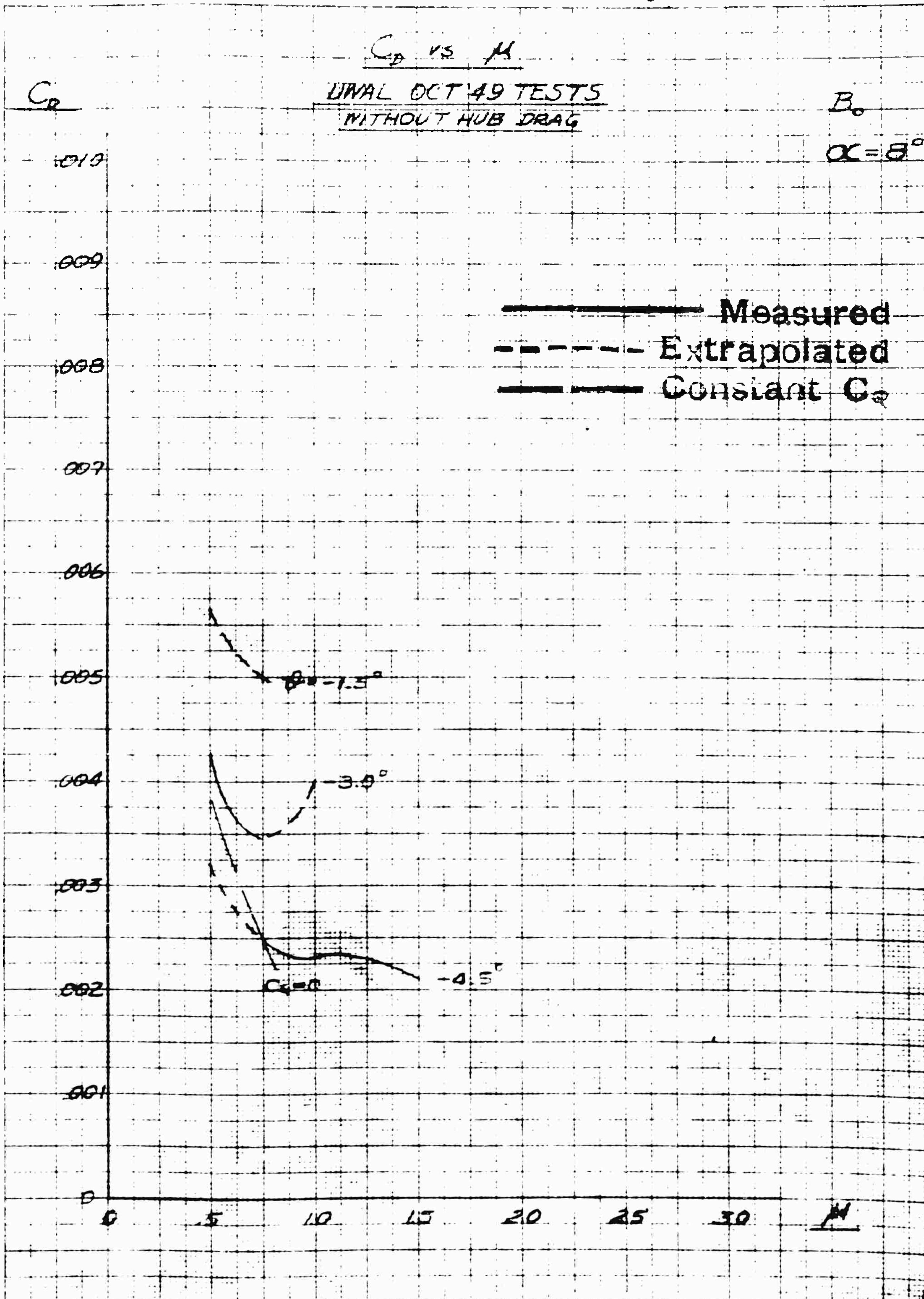
KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy

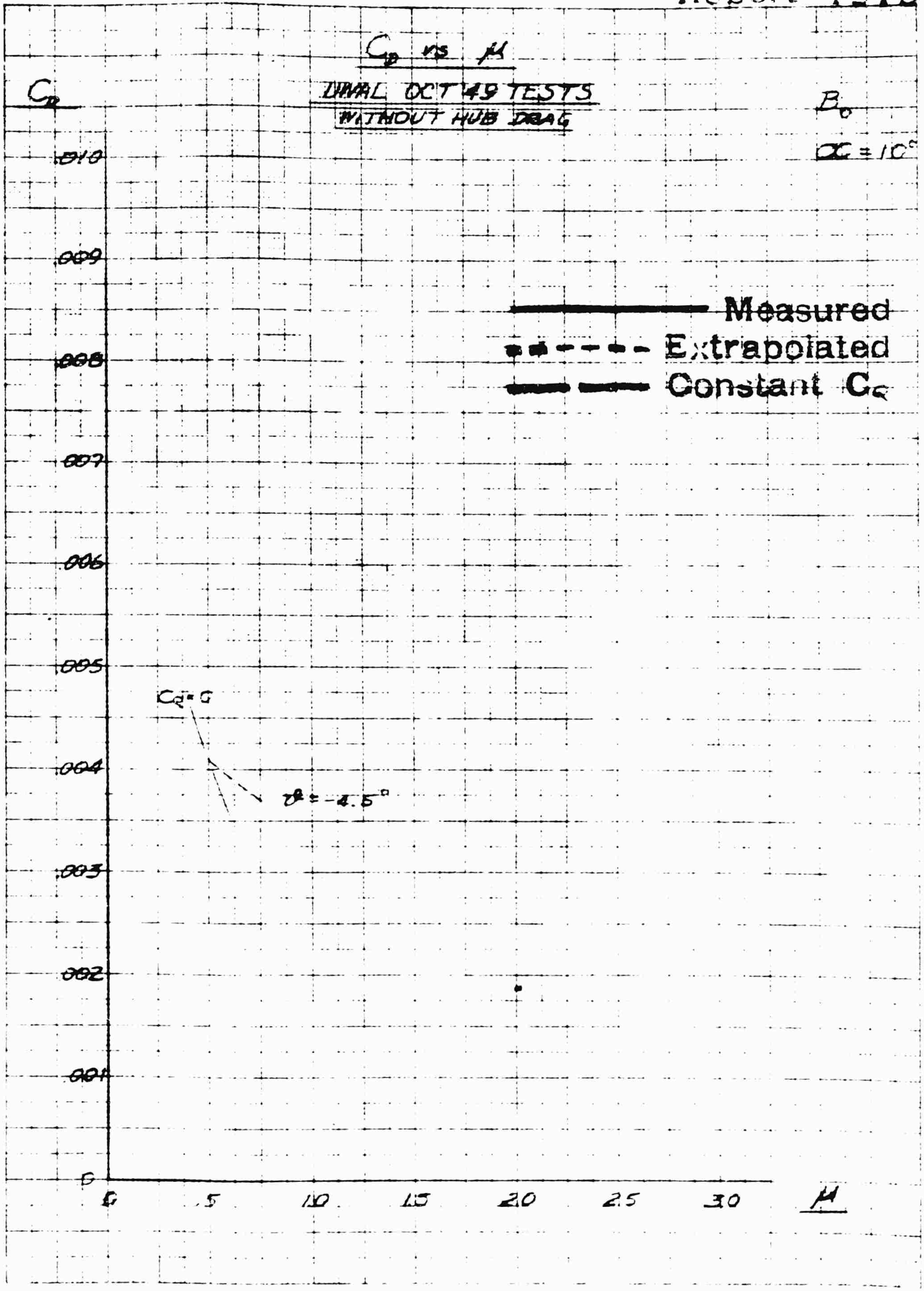
CONF



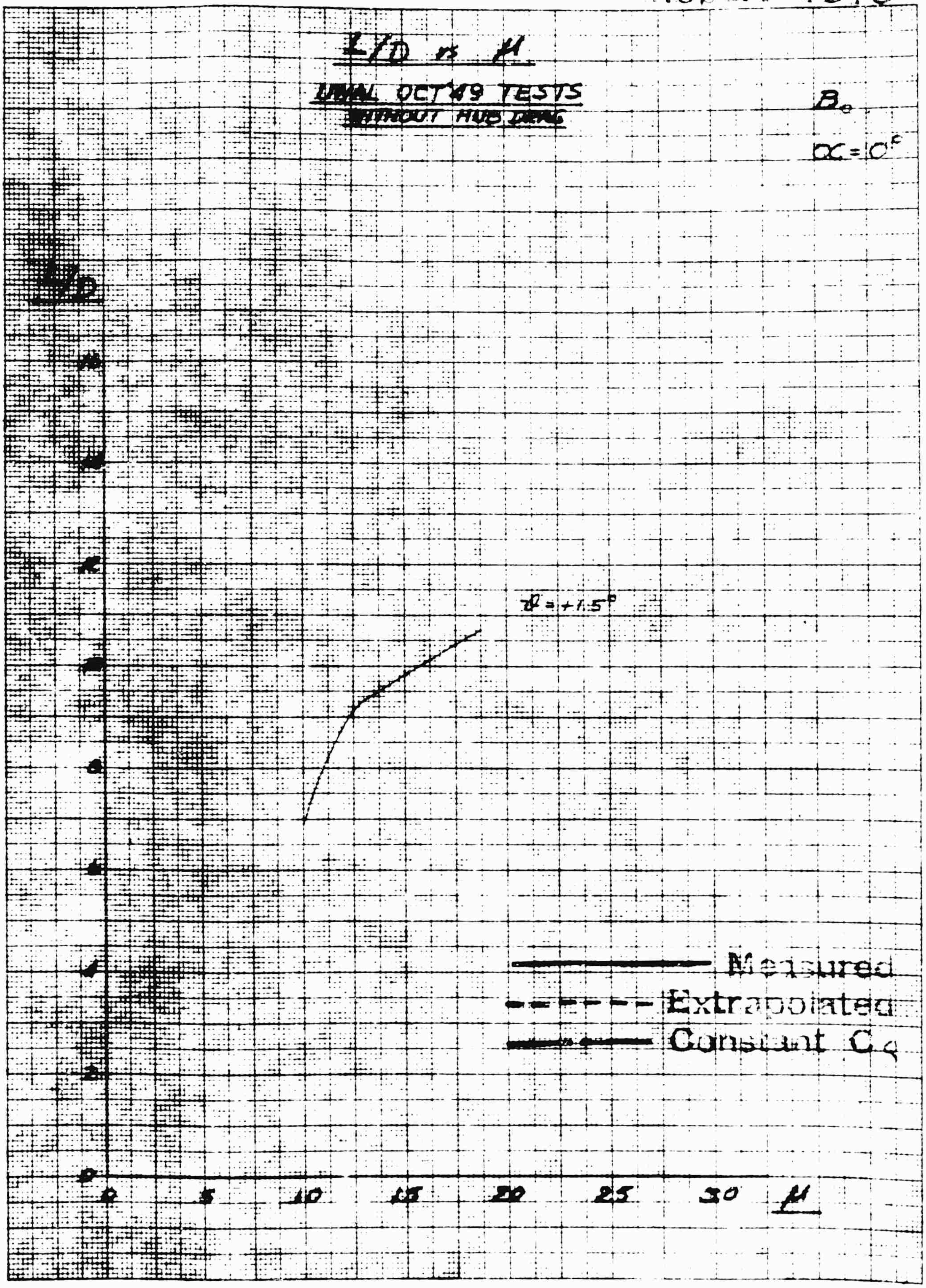
No. 359.14. Millimeters

CONFIDENTIAL

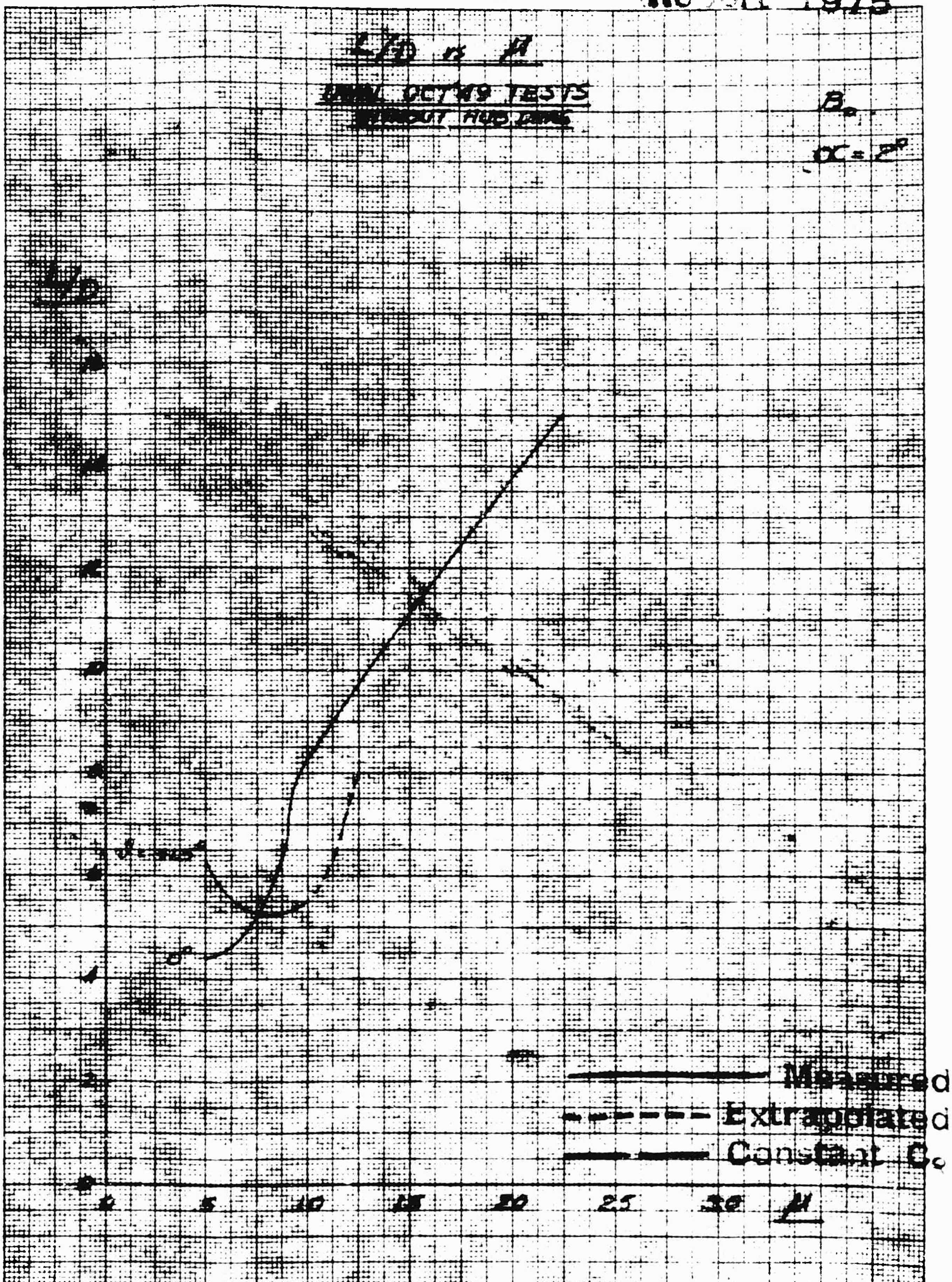

C_D vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
C_D
B_0
$\alpha = 8°$
Measured
Extrapolated
Constant C_L
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\beta = -1.5°$
$-3.0°$
$-4.5°$
$C_L = 0$
0
.5
1.0
1.5
2.0
2.5
3.0
μ



KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy



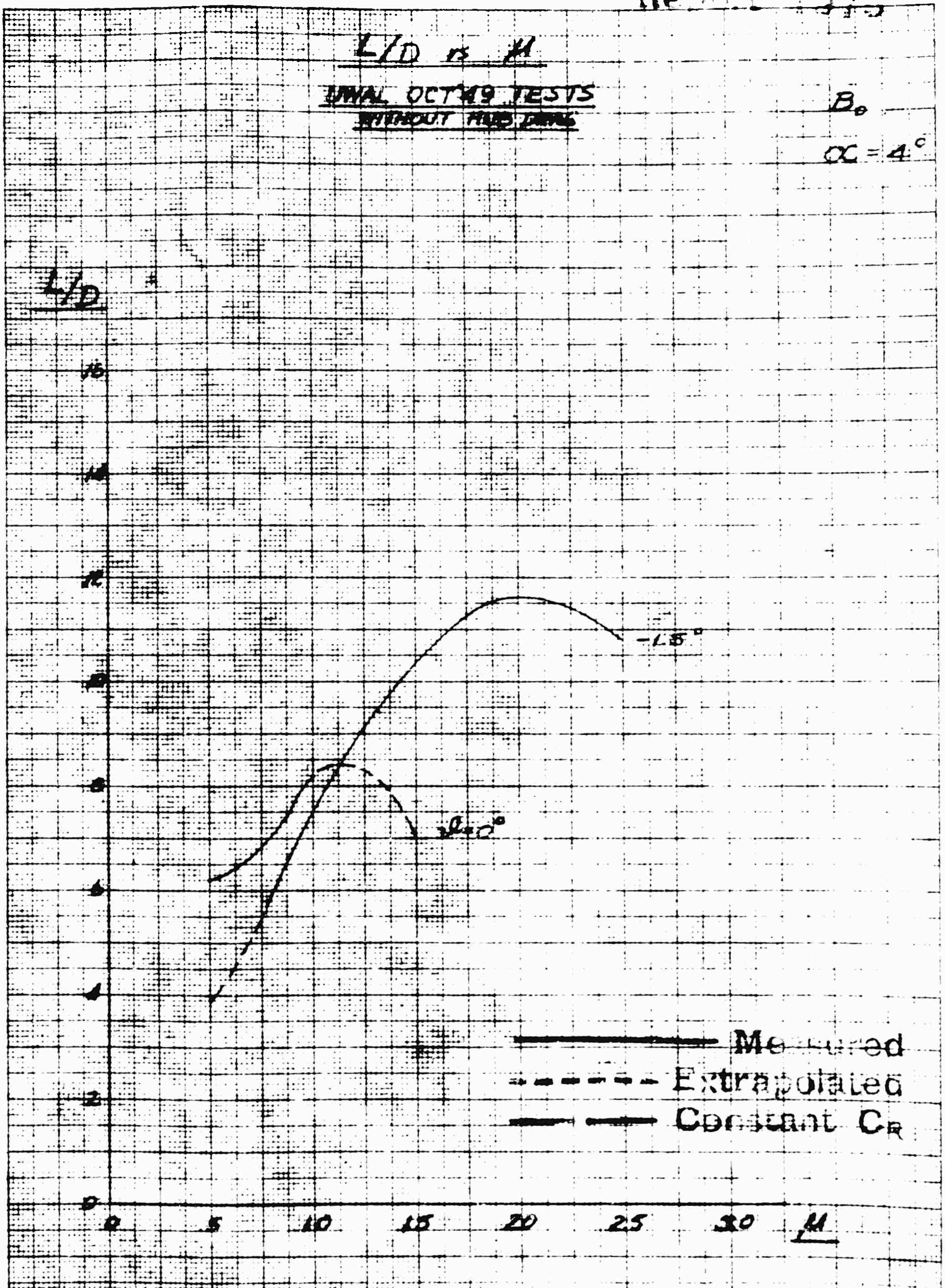
KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

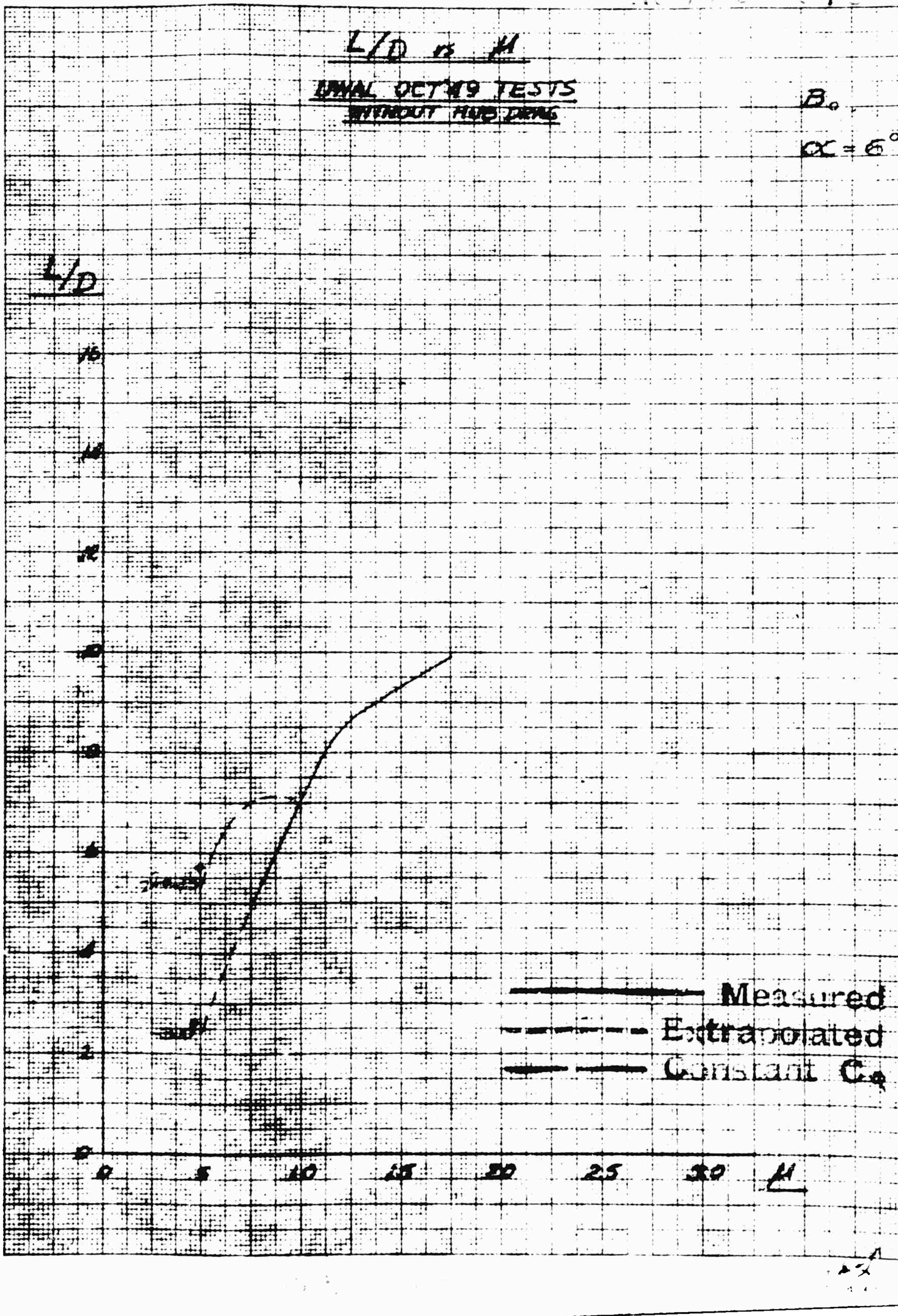
CONFIDENTIAL 141

Report 1375

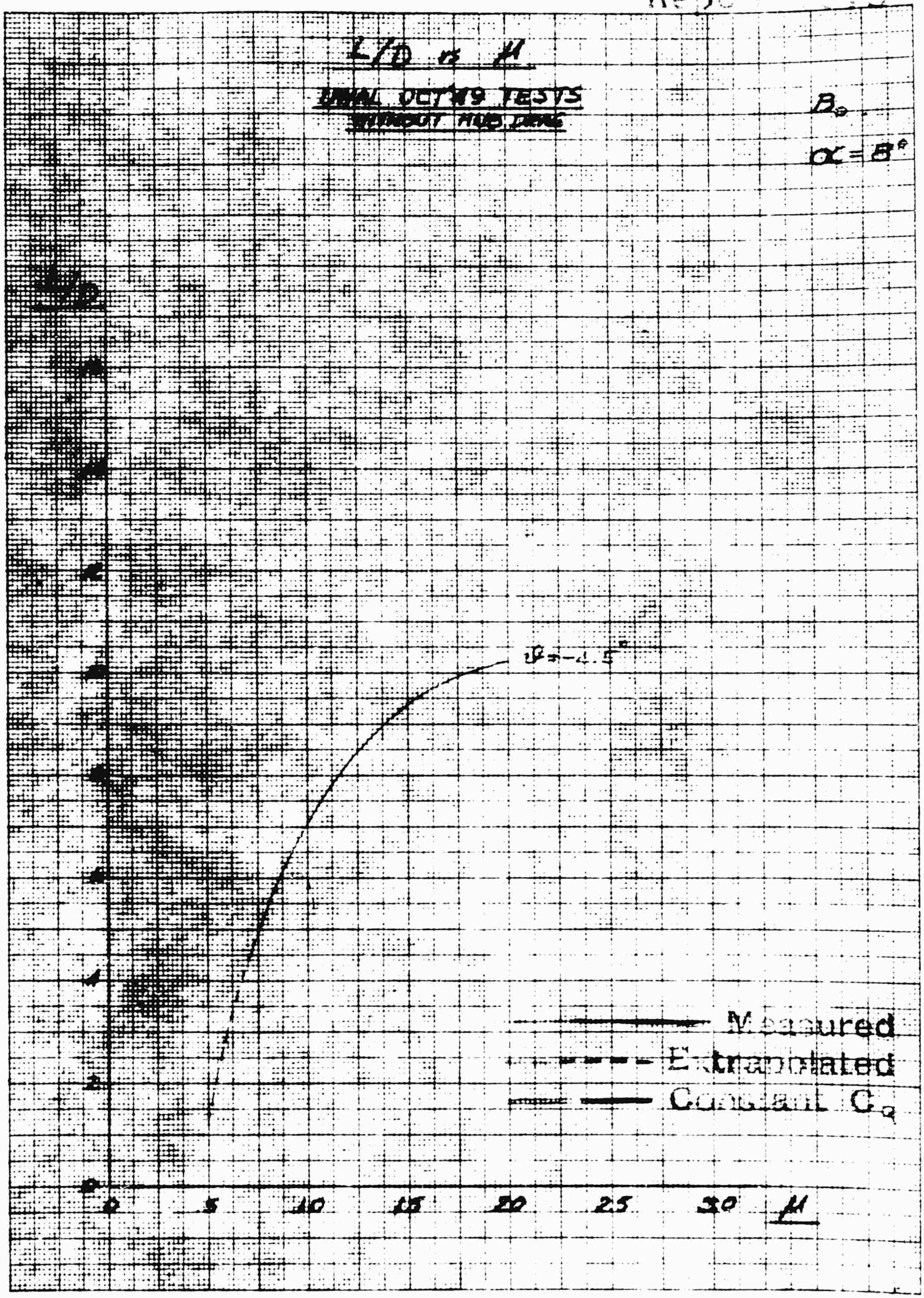


KEUFFEL & ESSER CO.

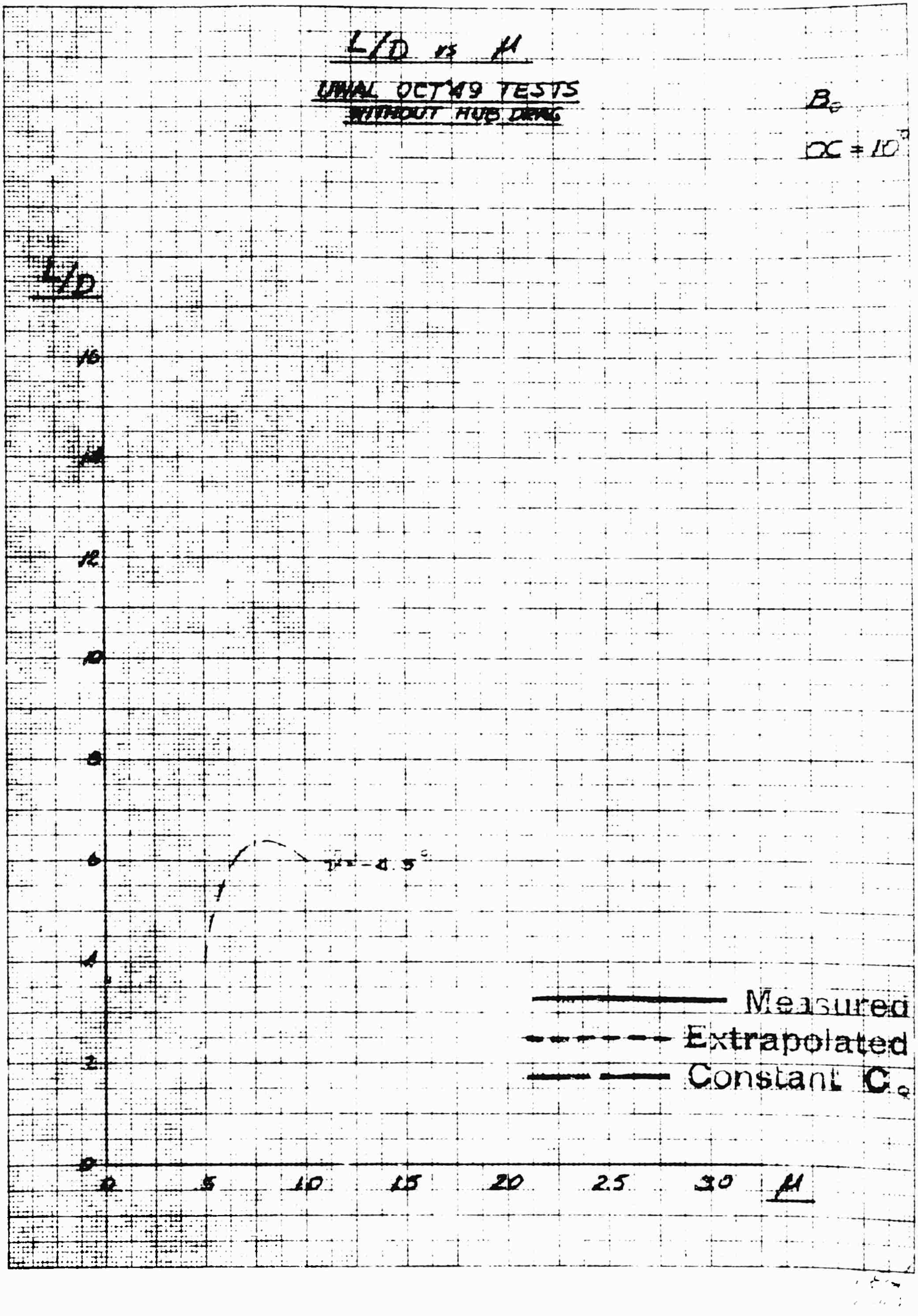
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



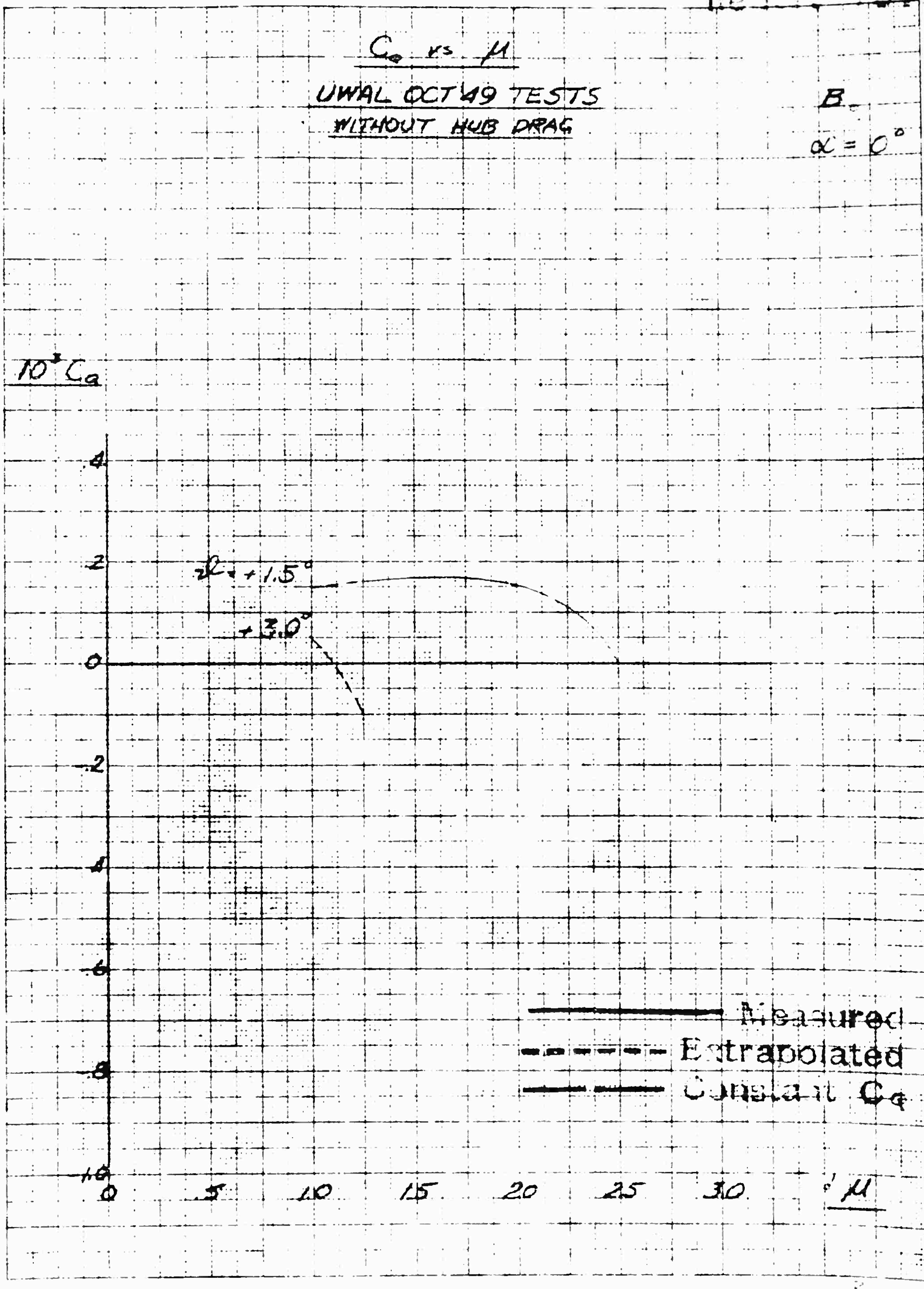
KEUFFEL & ESSER CO
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

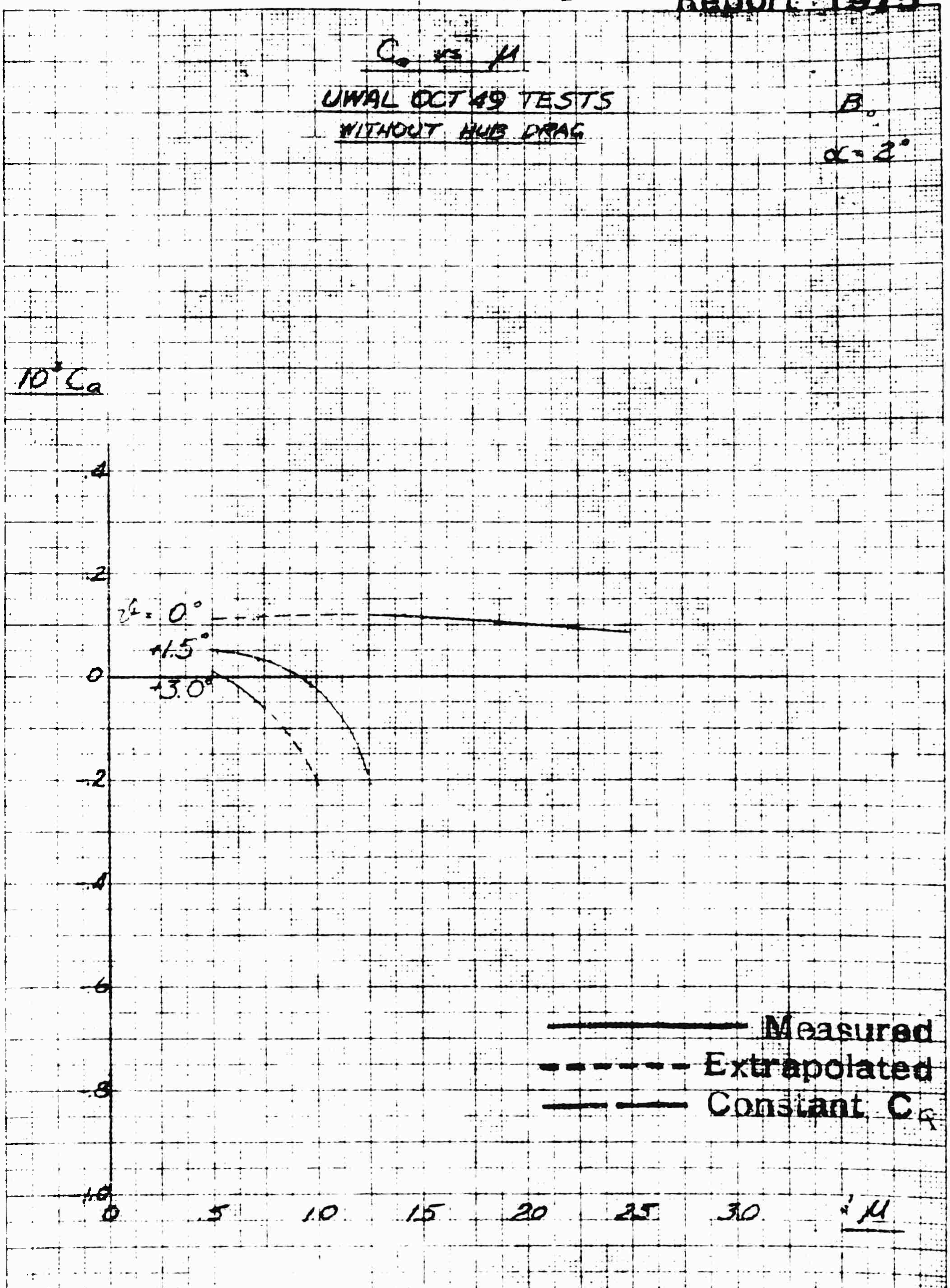


KEUFFEL & ESSER CO.
No. 359 11 Millimeters, 5 mm lines accented, cm lines heavy



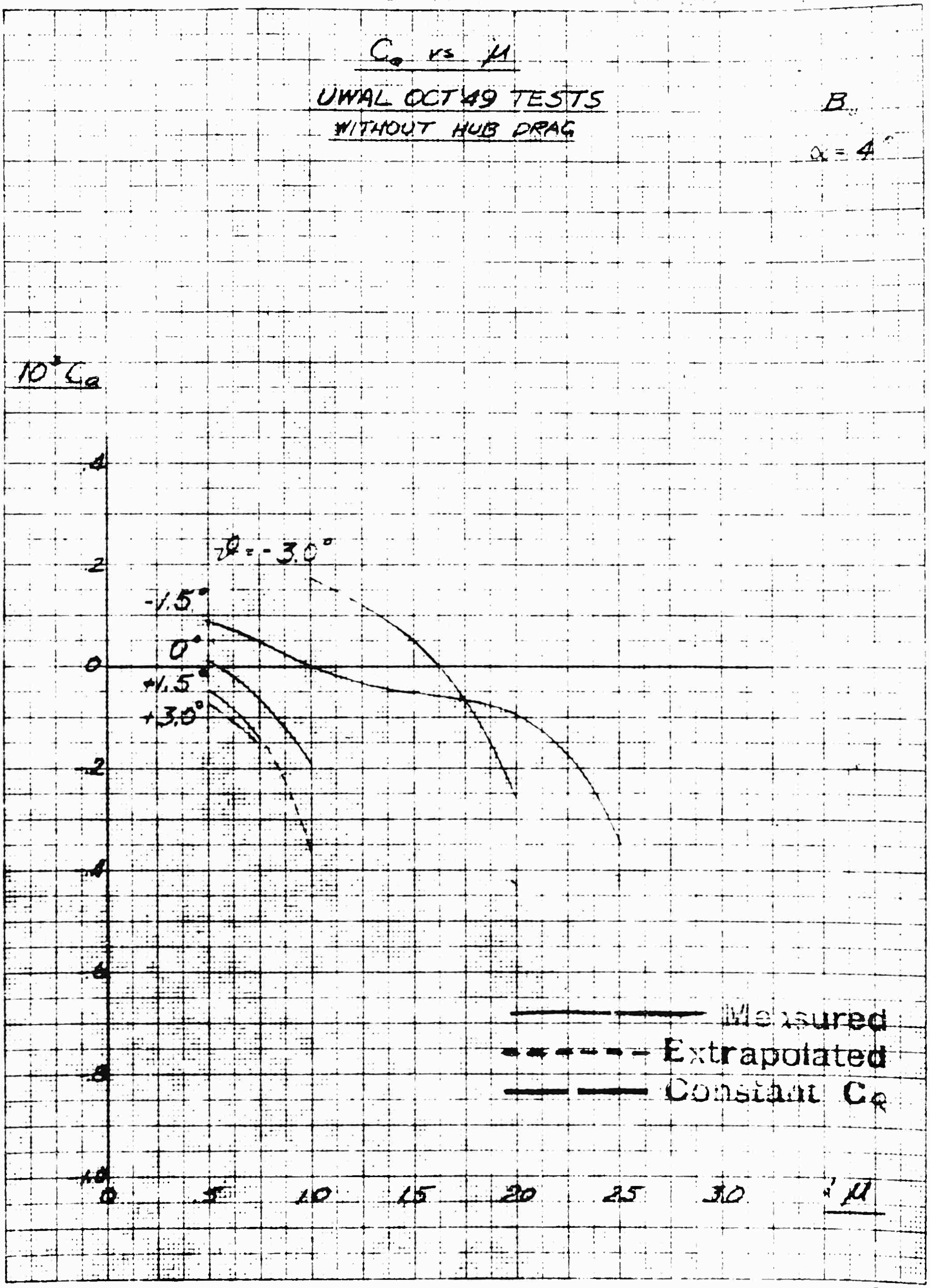
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy


Cq vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
α = 0°
10³ Cq
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
θ = +1.5°
+3.0°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant Cq


C_a vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B_o
$\alpha = 2°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
$\theta = 0°$
+1.5°
+3.0°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_R

RCS

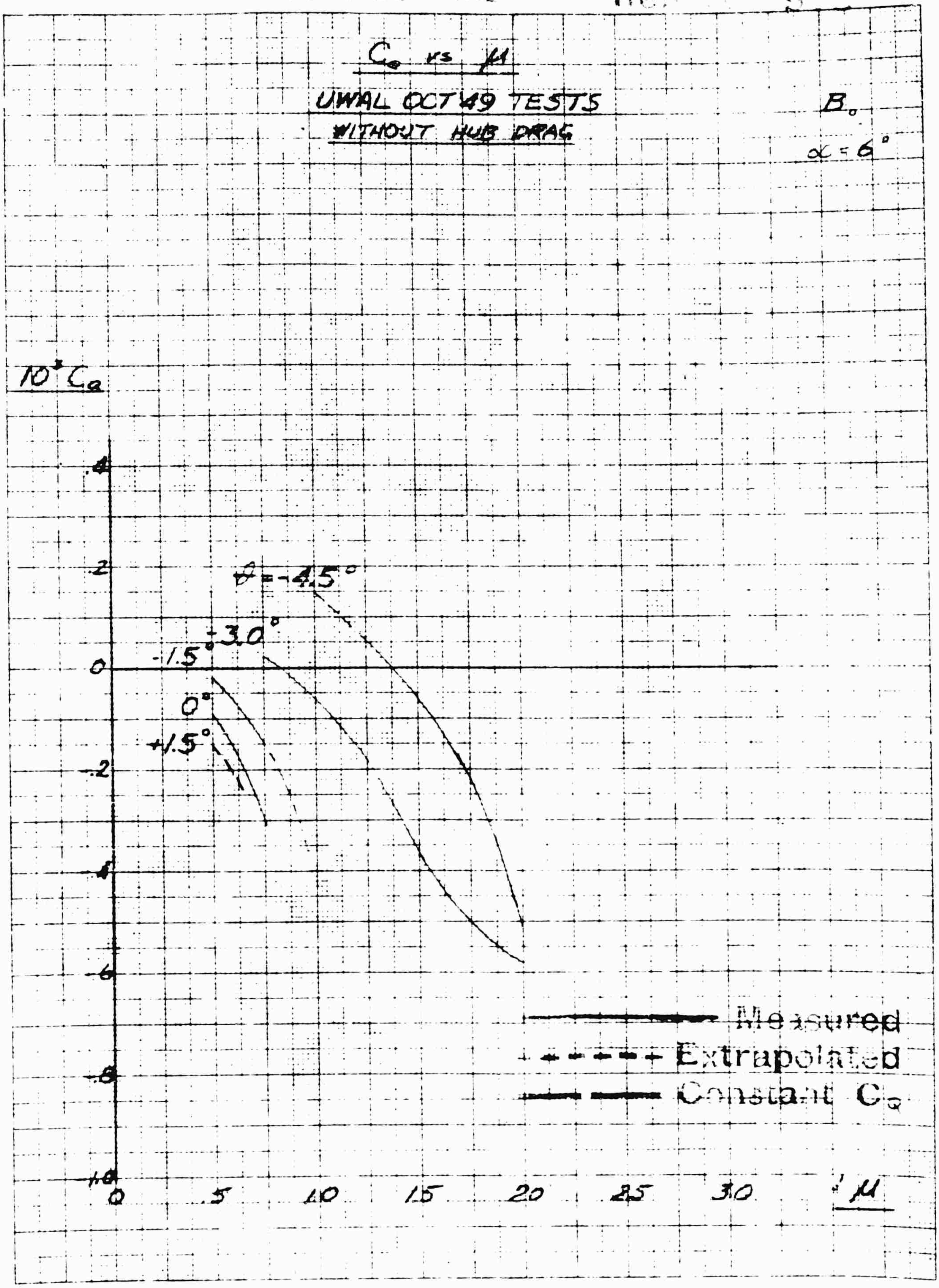
CONFIDENTIAL



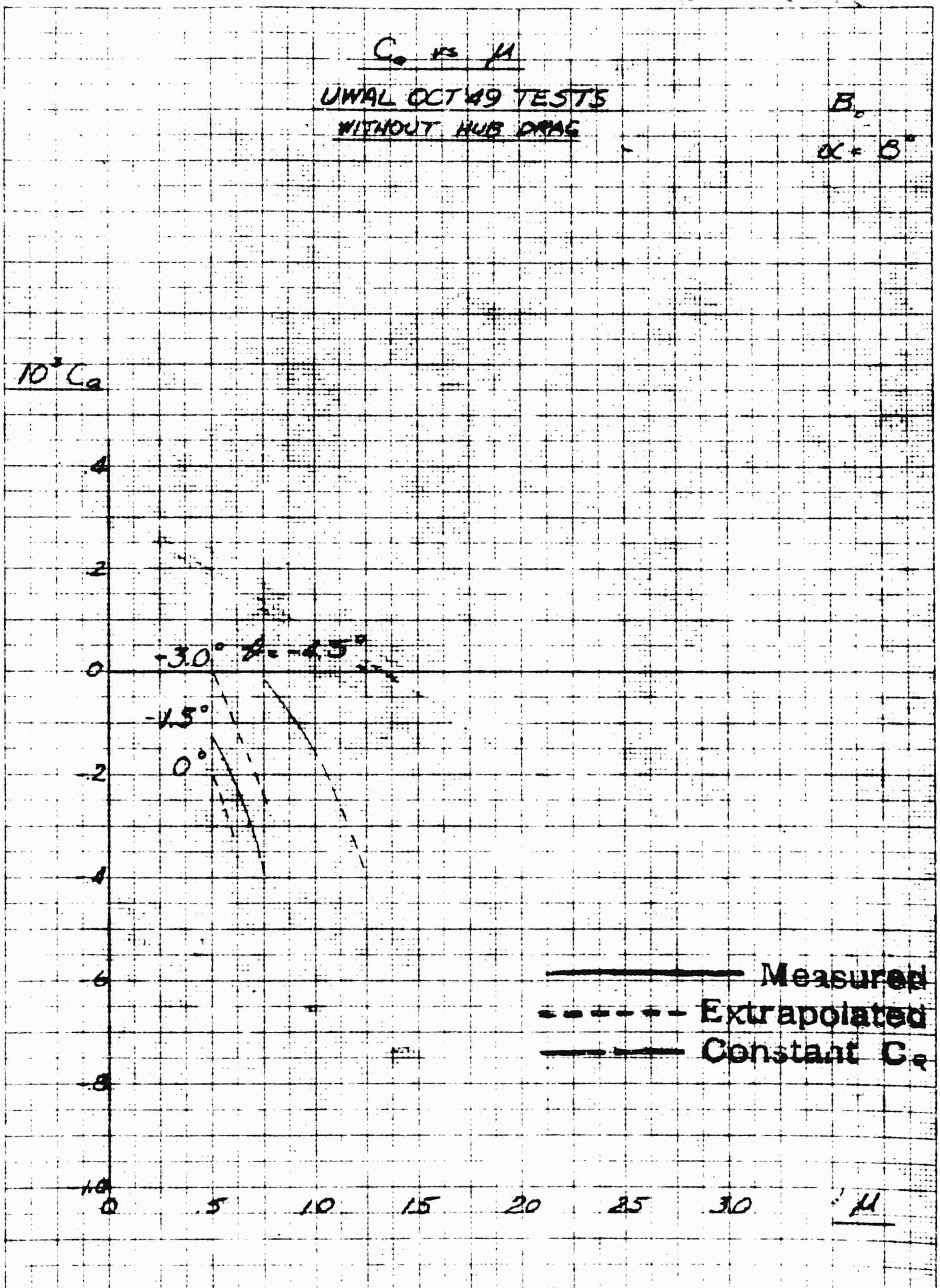
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

CONFIDENTIAL

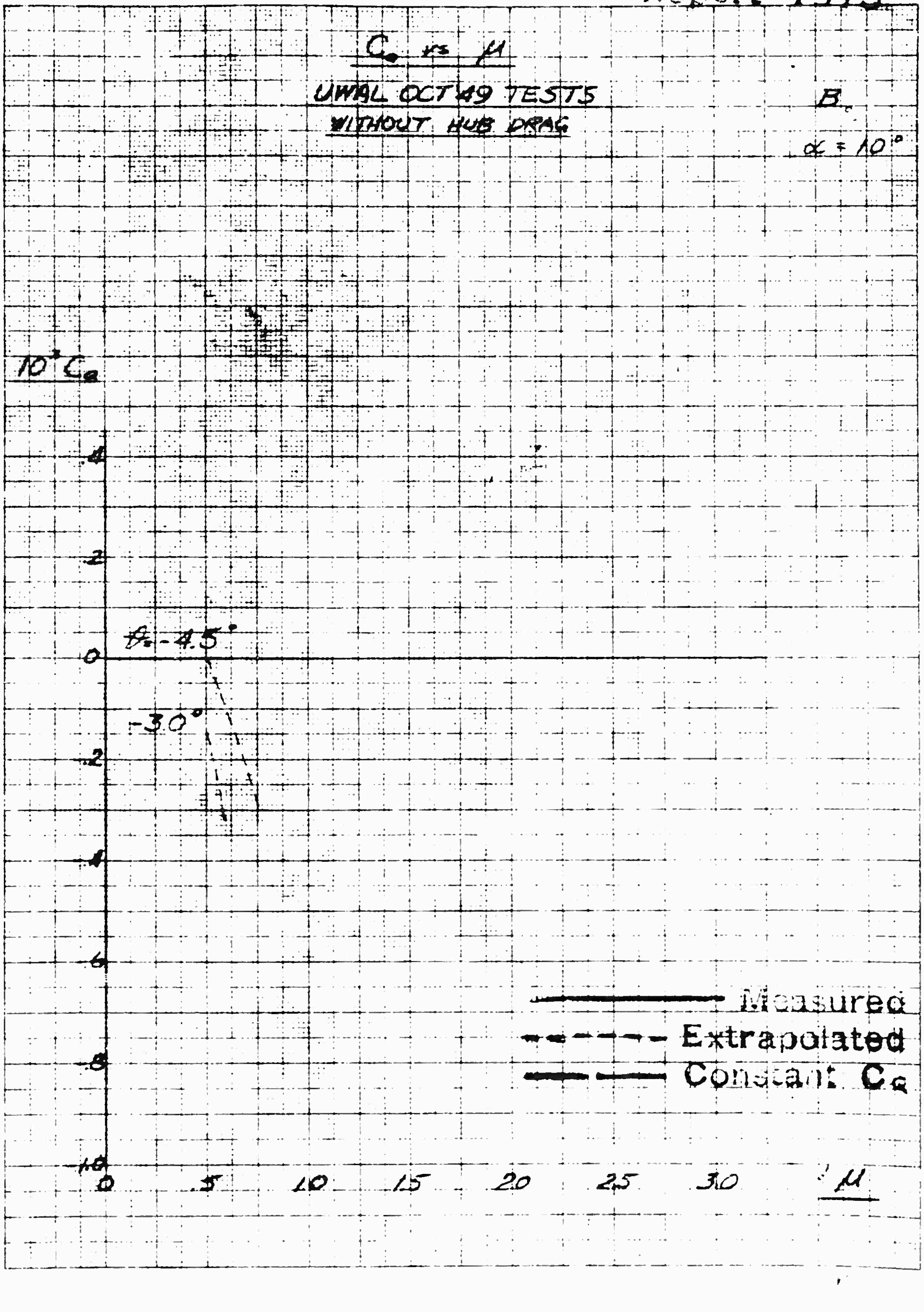


KEUFFEL & ESSER CO.

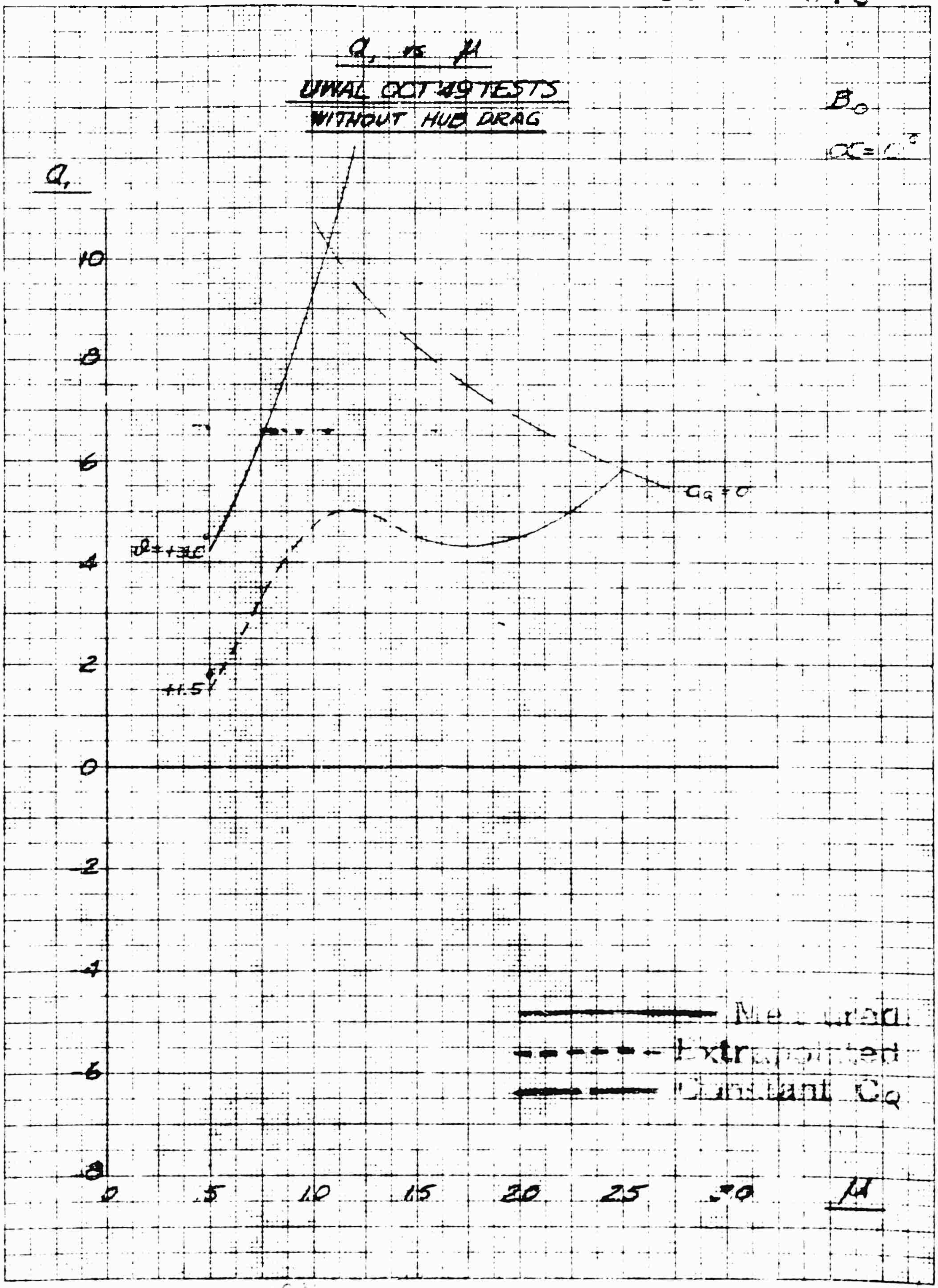


CONFIDENTIAL

CONFIDENTIAL



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm. lines accented, cm. lines heavy.

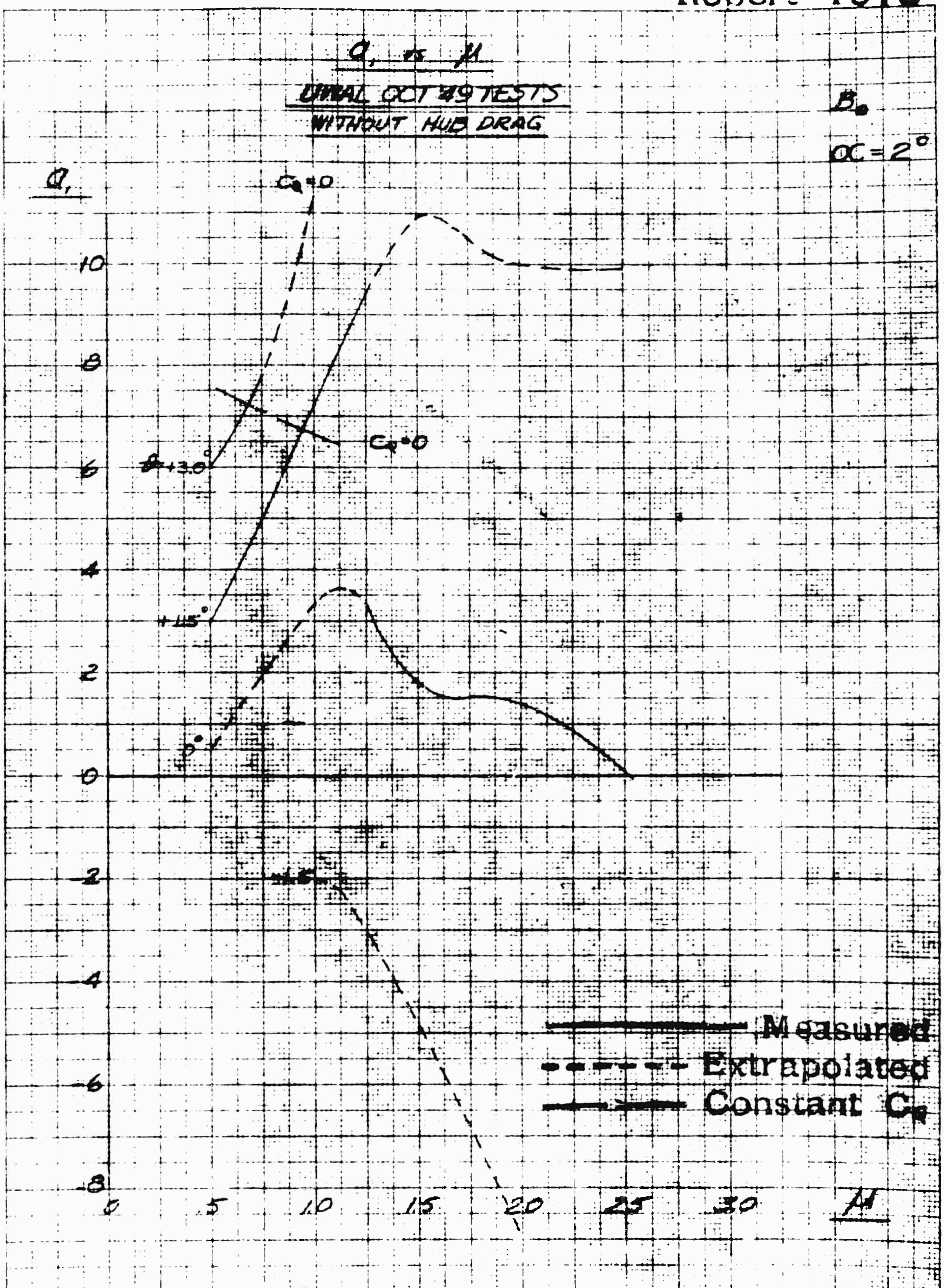


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines, accented cm lines, heavy.

CONFIDENTIAL

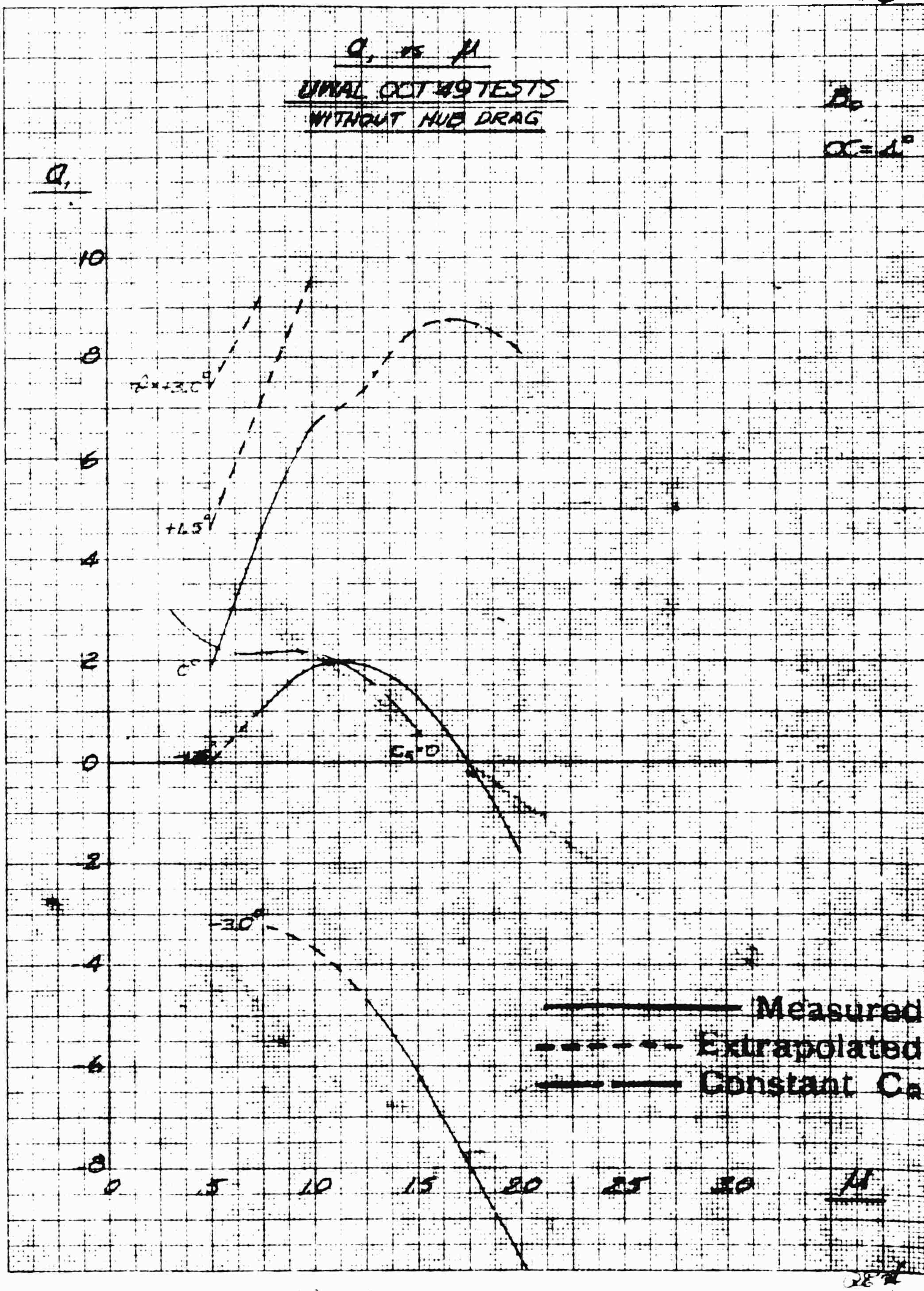
152

Report 1975



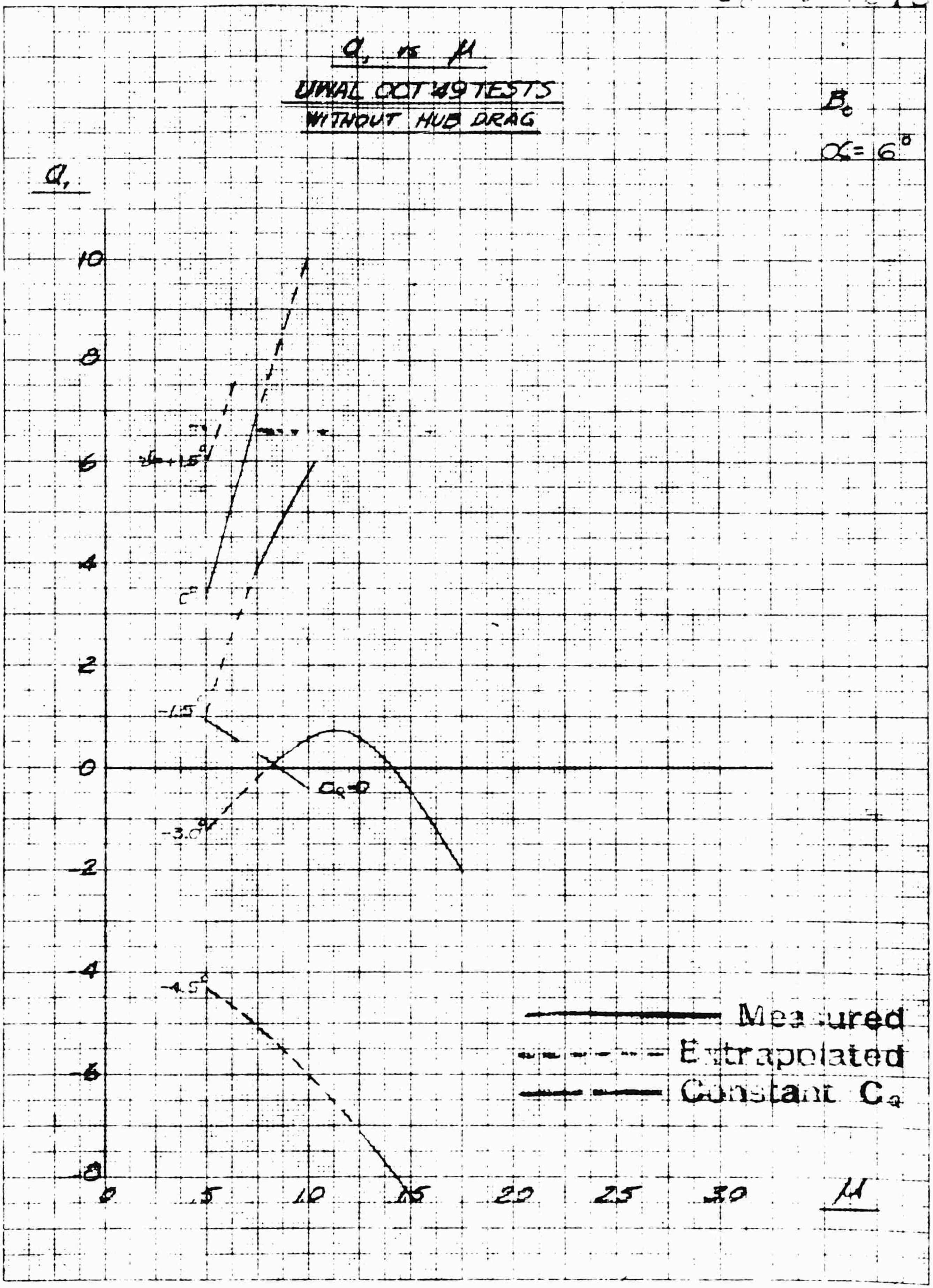
P.E.Z.
12-14-49

KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy

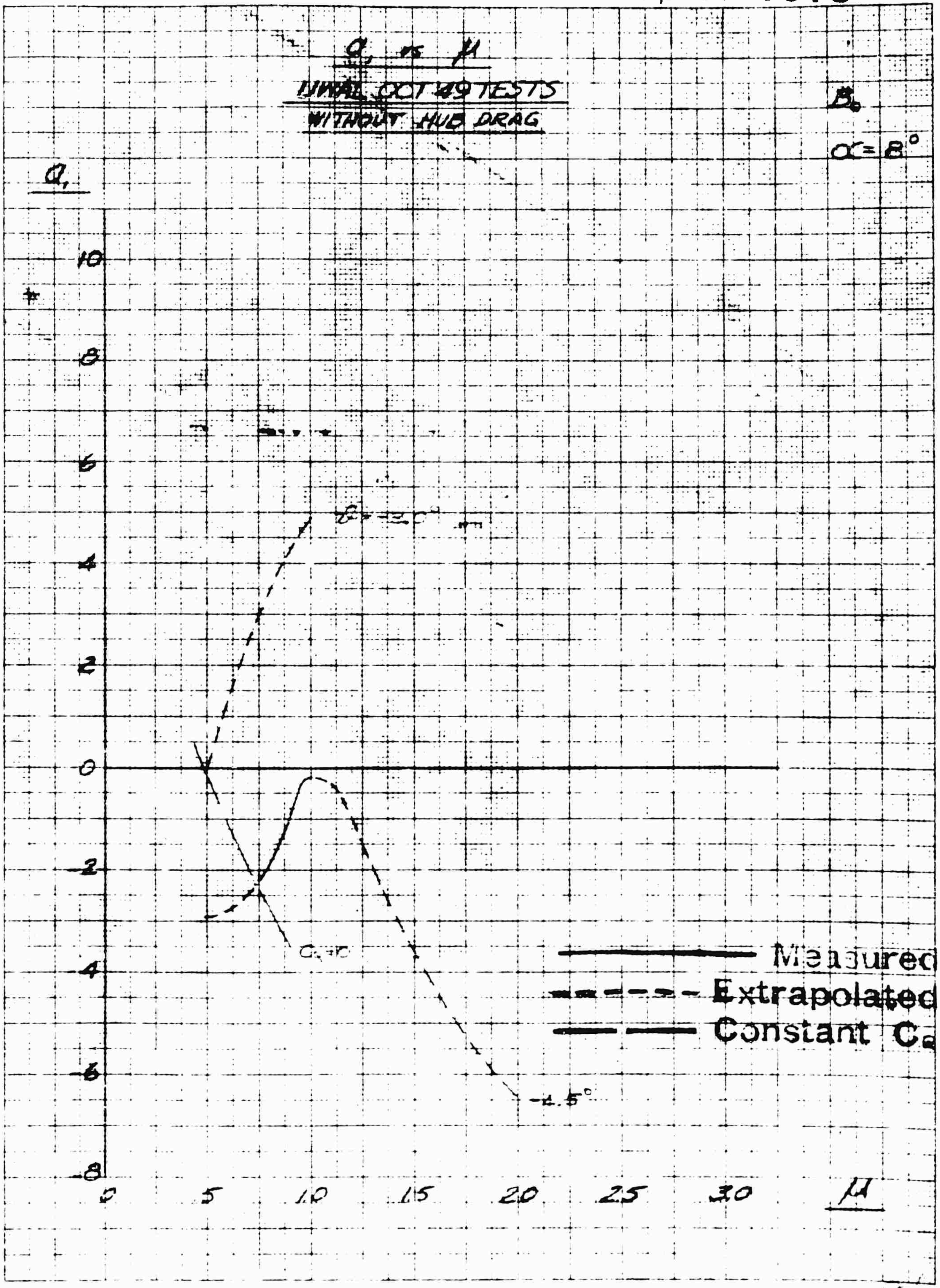


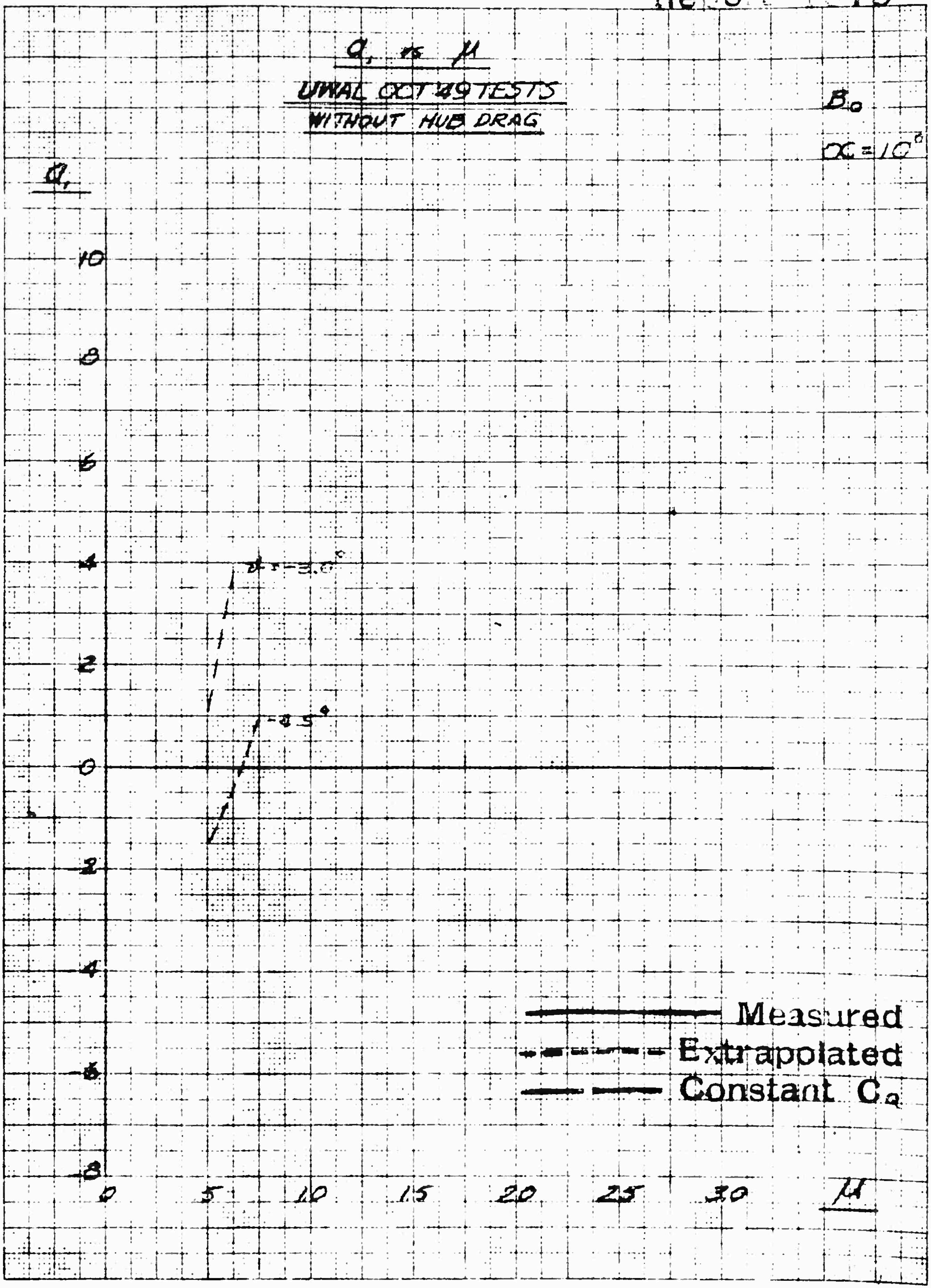
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
KEUFFEL & ESSER CO.

12 14 49

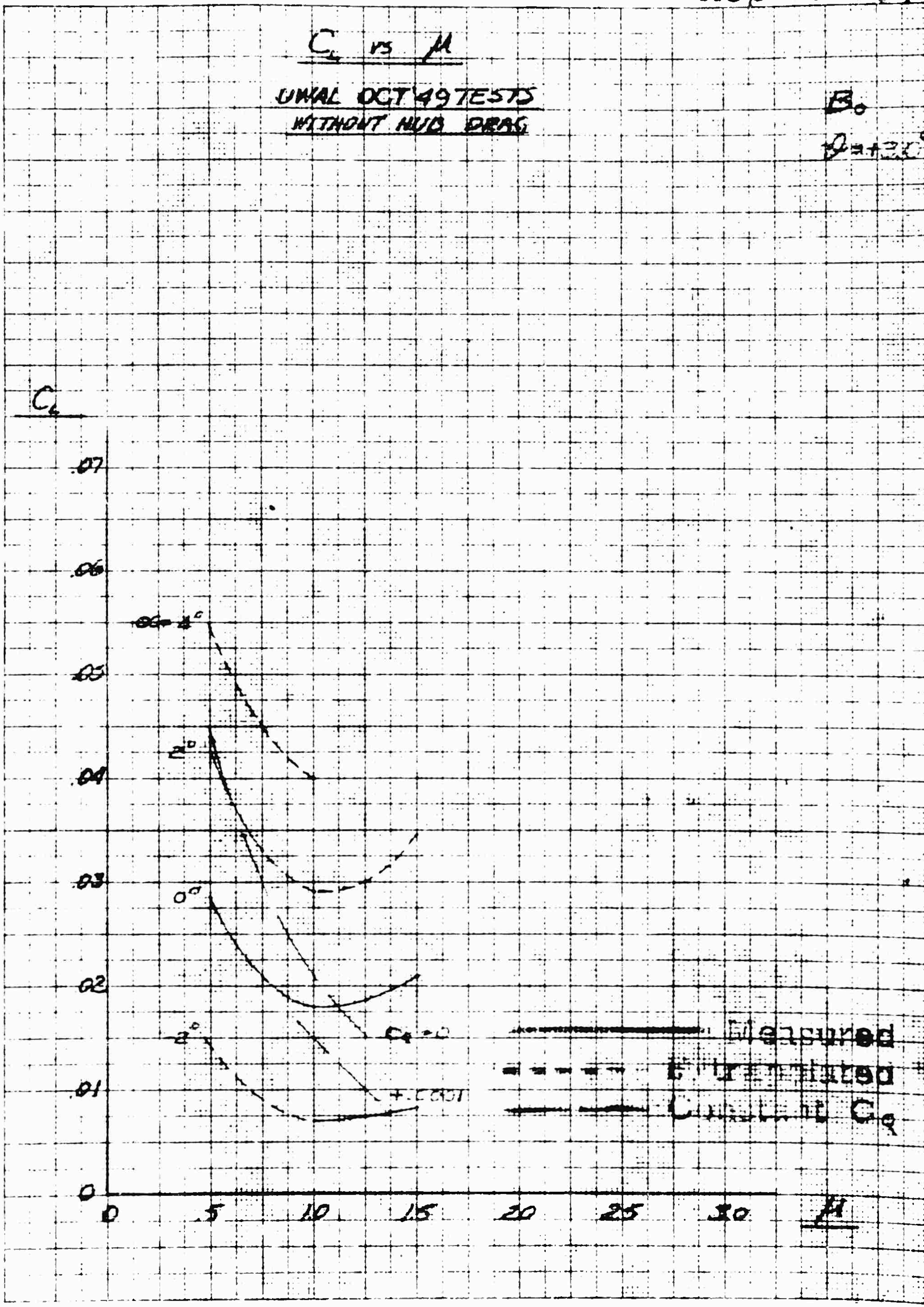


KEUFFEL & ESSER CO.

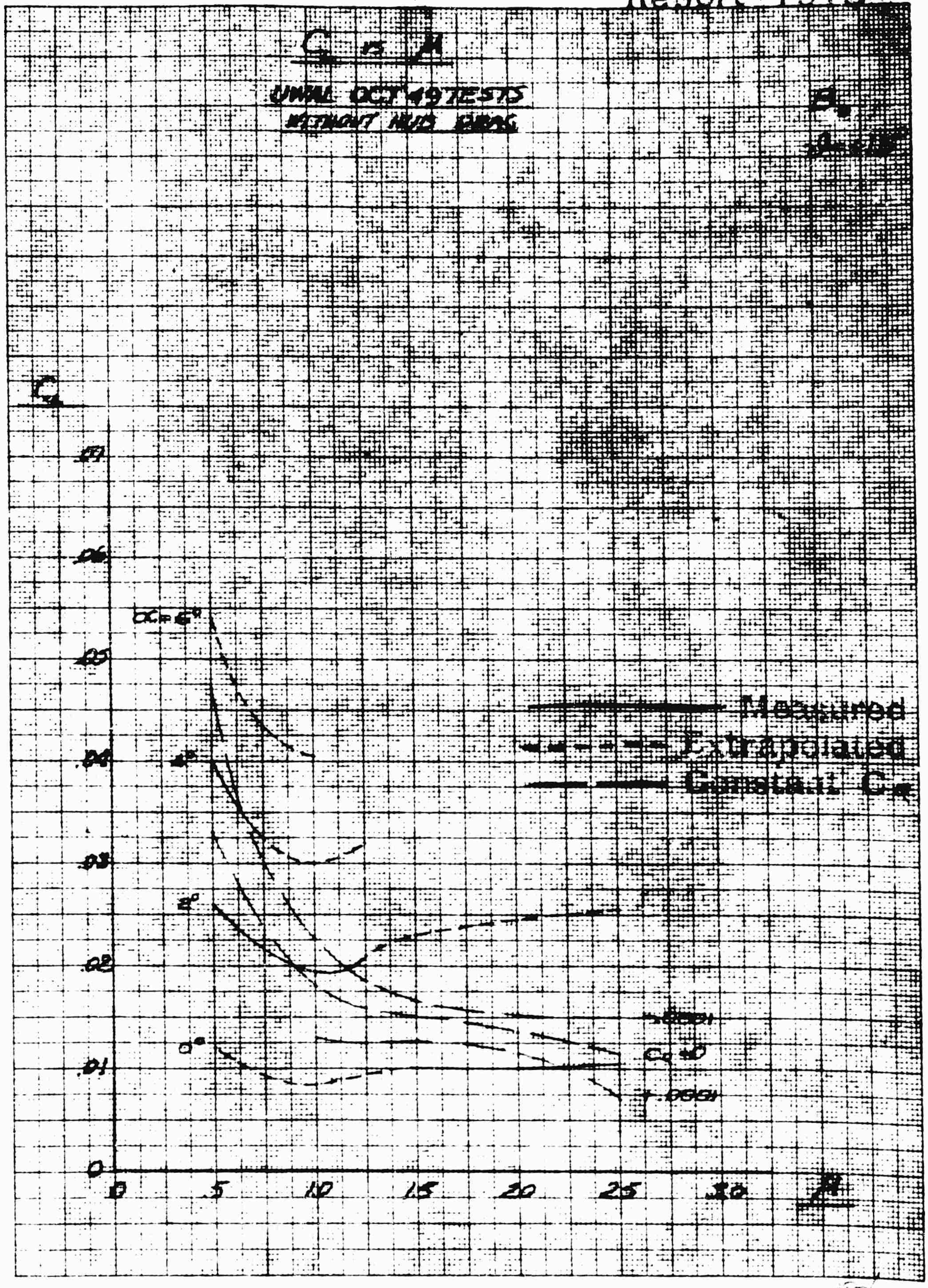

a_1 vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\alpha = 8°$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
0
.5
1.0
1.5
2.0
2.5
3.0
μ
$\theta = 2.0°$
$-4.5°$
Measured
Extrapolated
Constant C_a



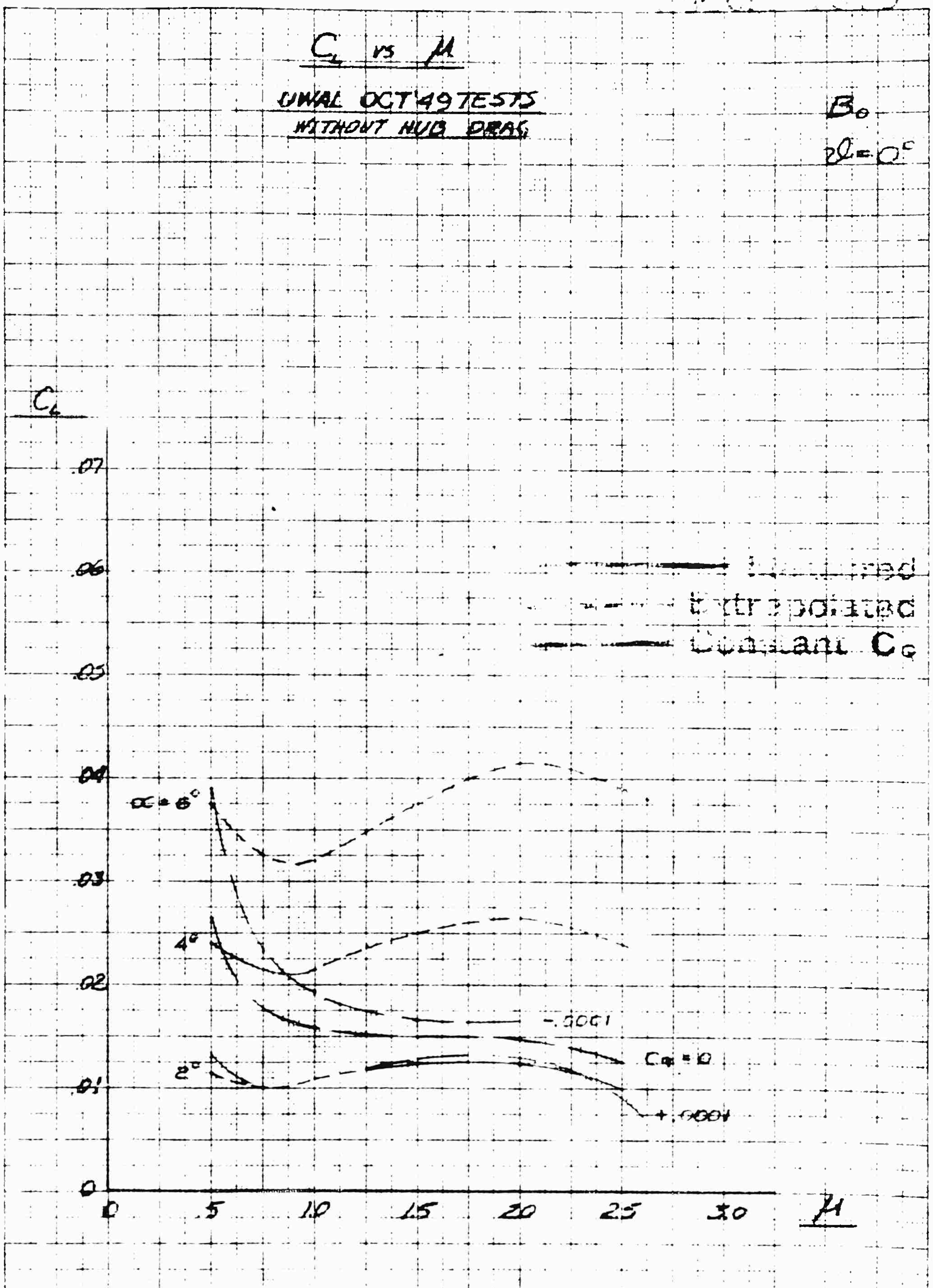
KEUFFEL & ESSER CO
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



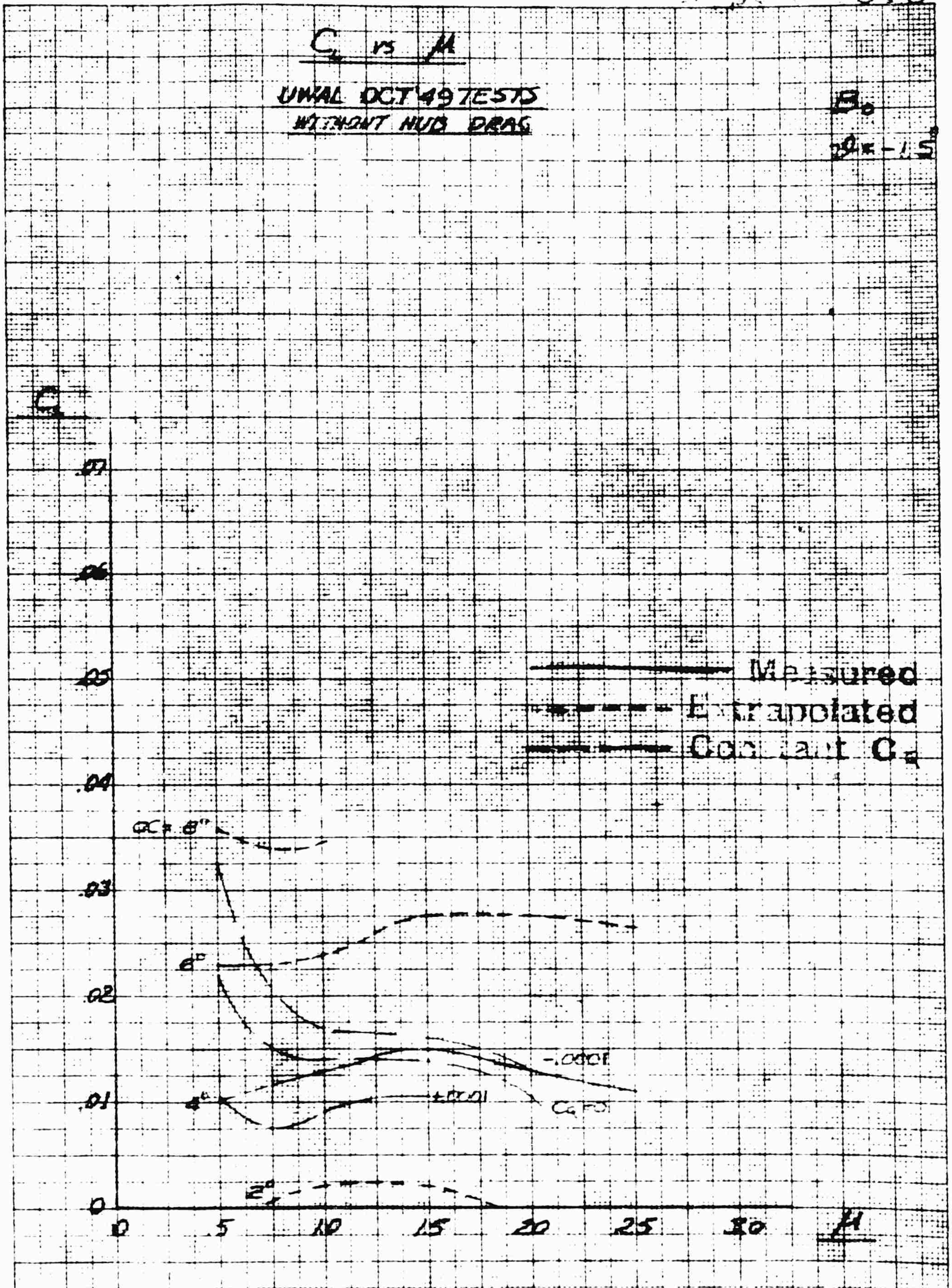
KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.



KEUFFEL & ESSER CO
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

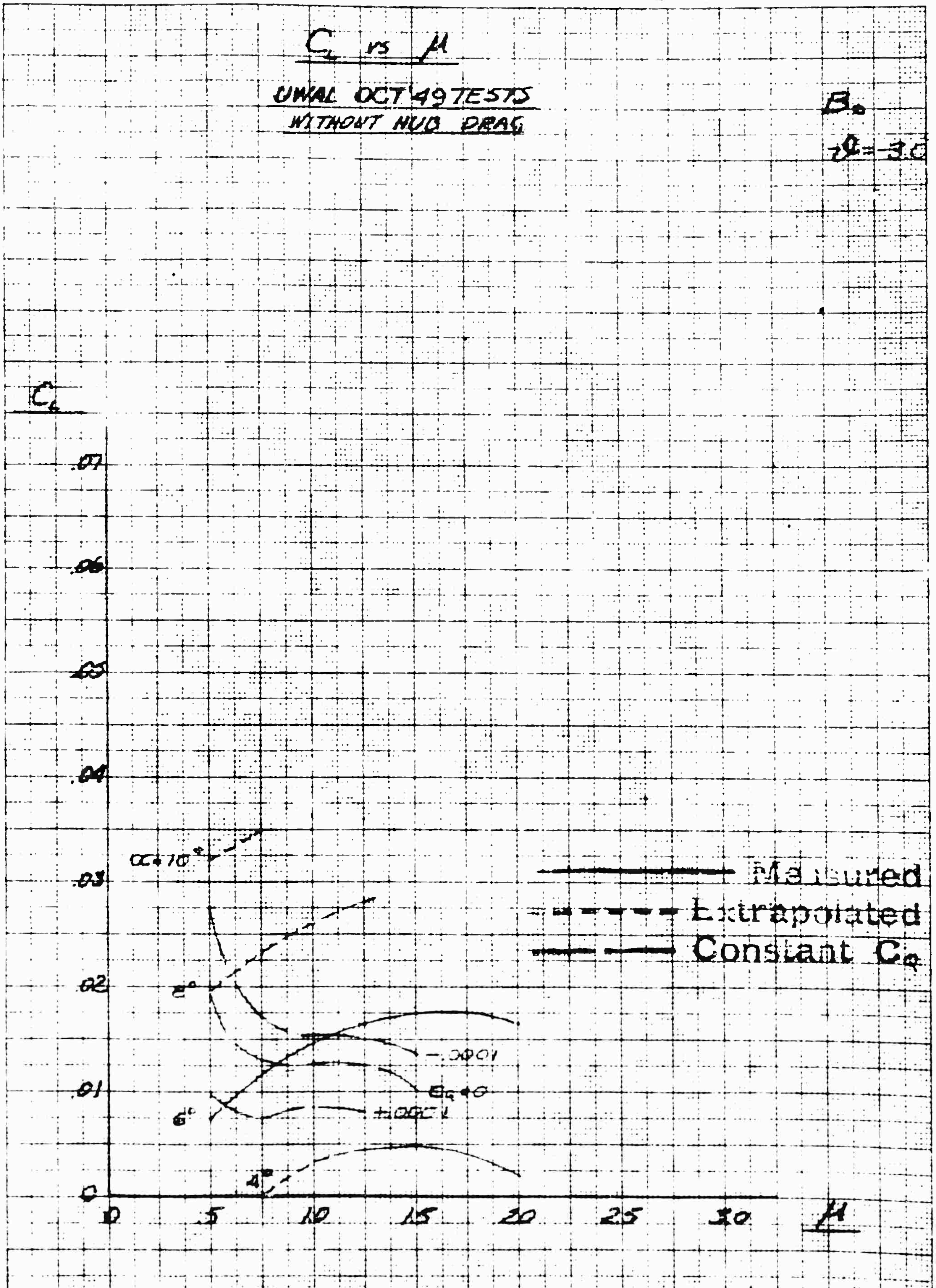
160

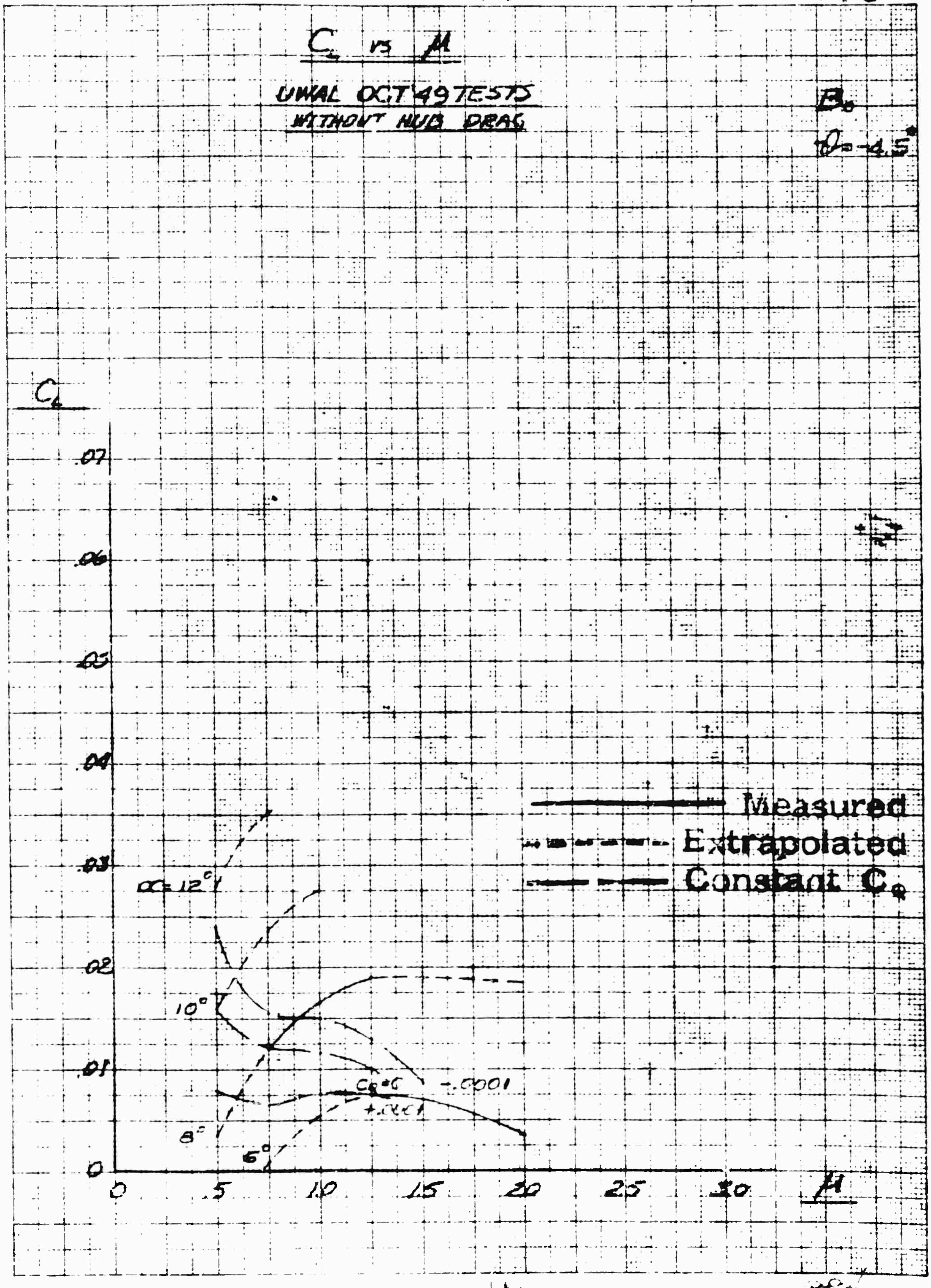
1975



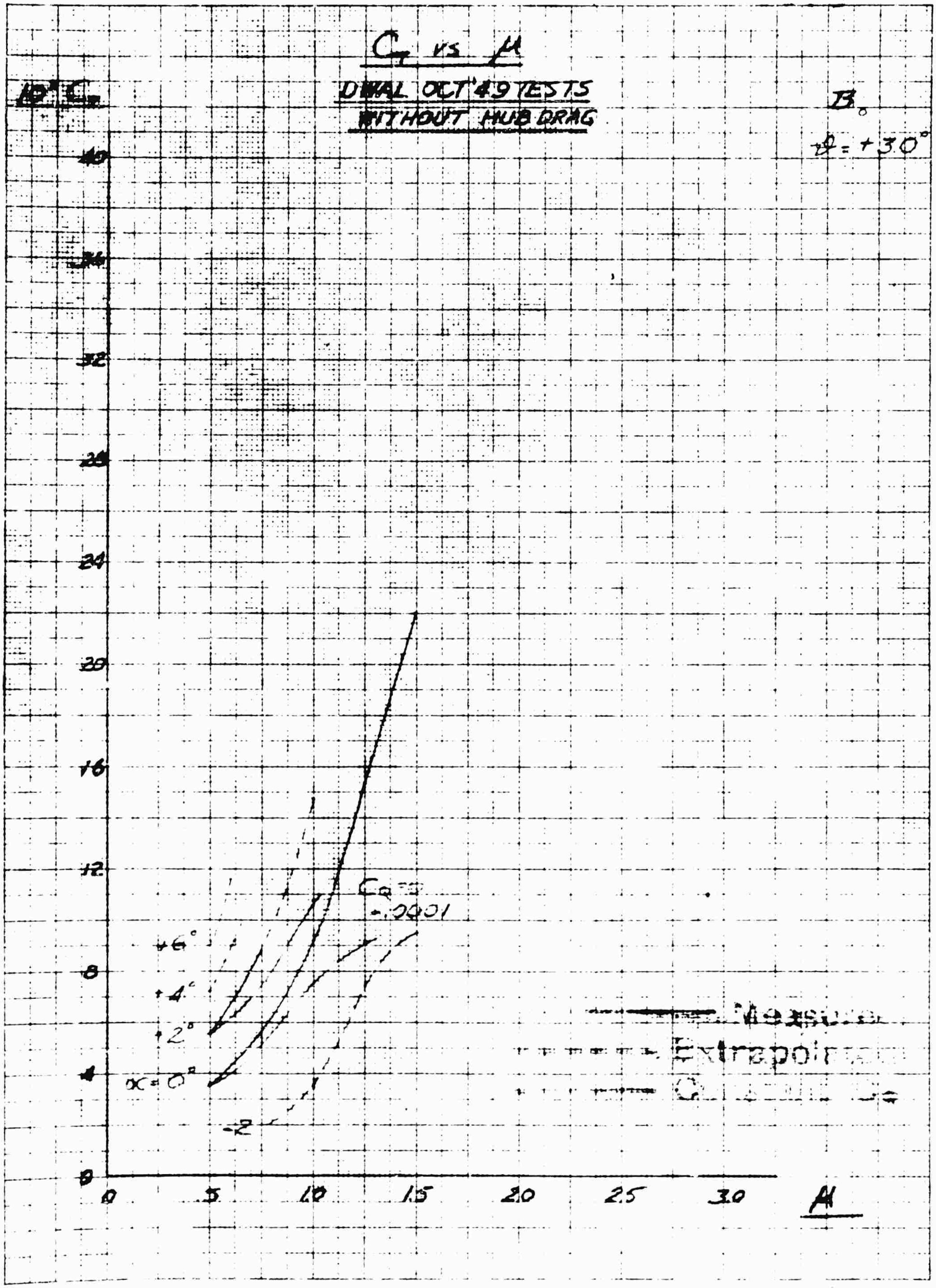
KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

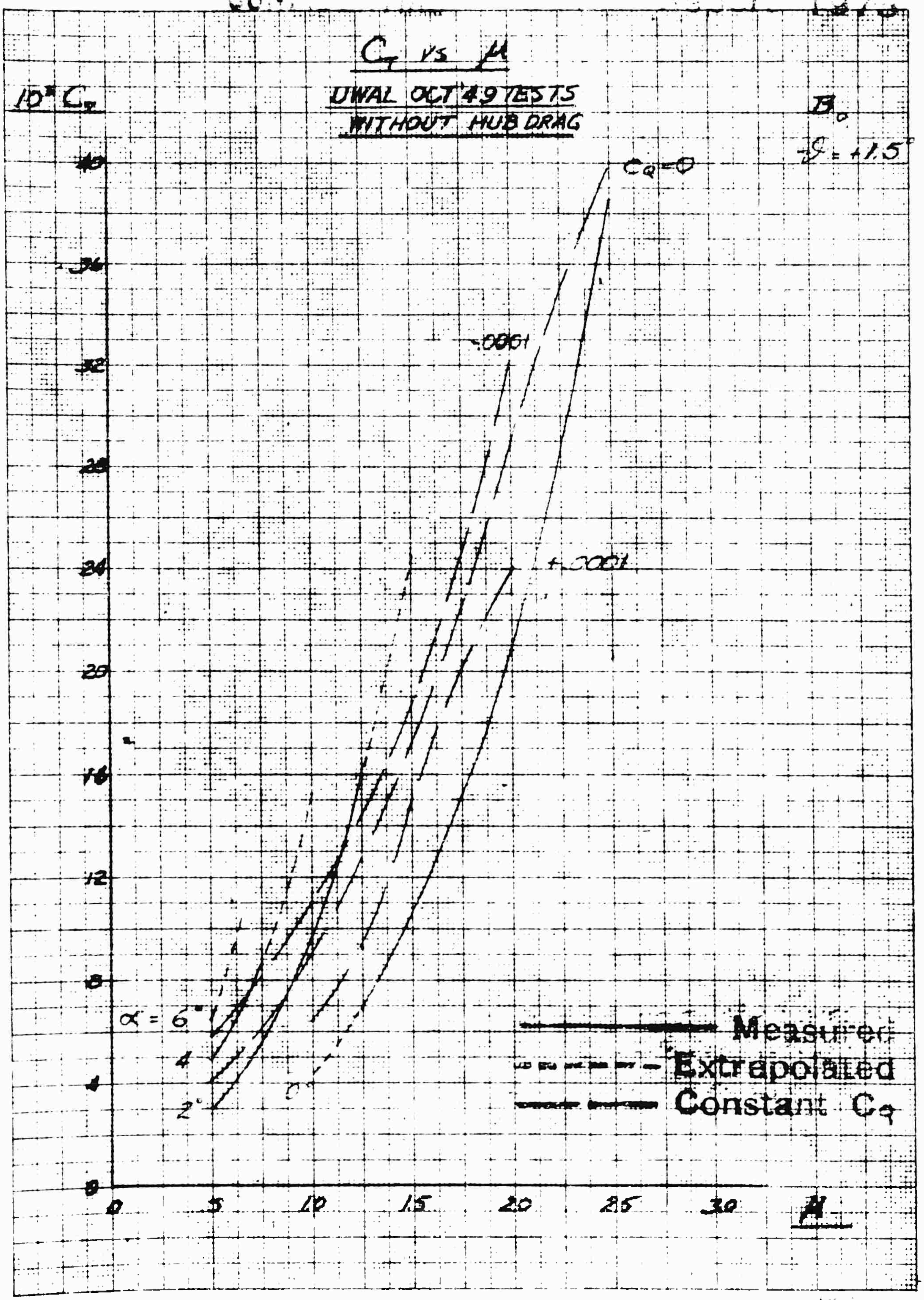

C_L vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$\theta = 3.0$
C_L
.07
.06
.05
.04
.03
.02
.01
0
$\alpha = 10°$
8°
6°
4°
-.0001
$C_Q = 0$
+.0001
0
.5
.10
.15
.20
.25
.30
μ
Measured
Extrapolated
Constant C_Q



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

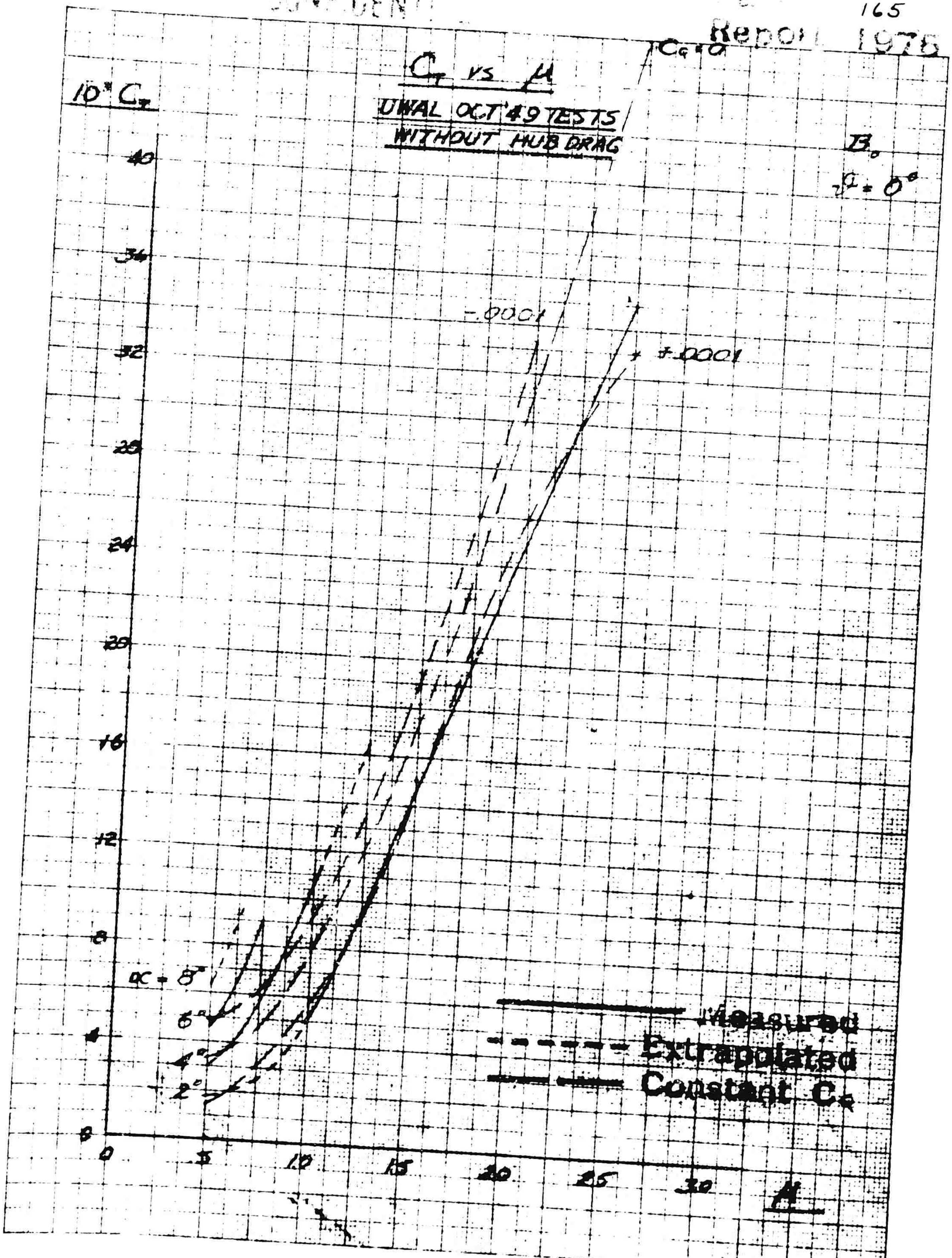


KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy.



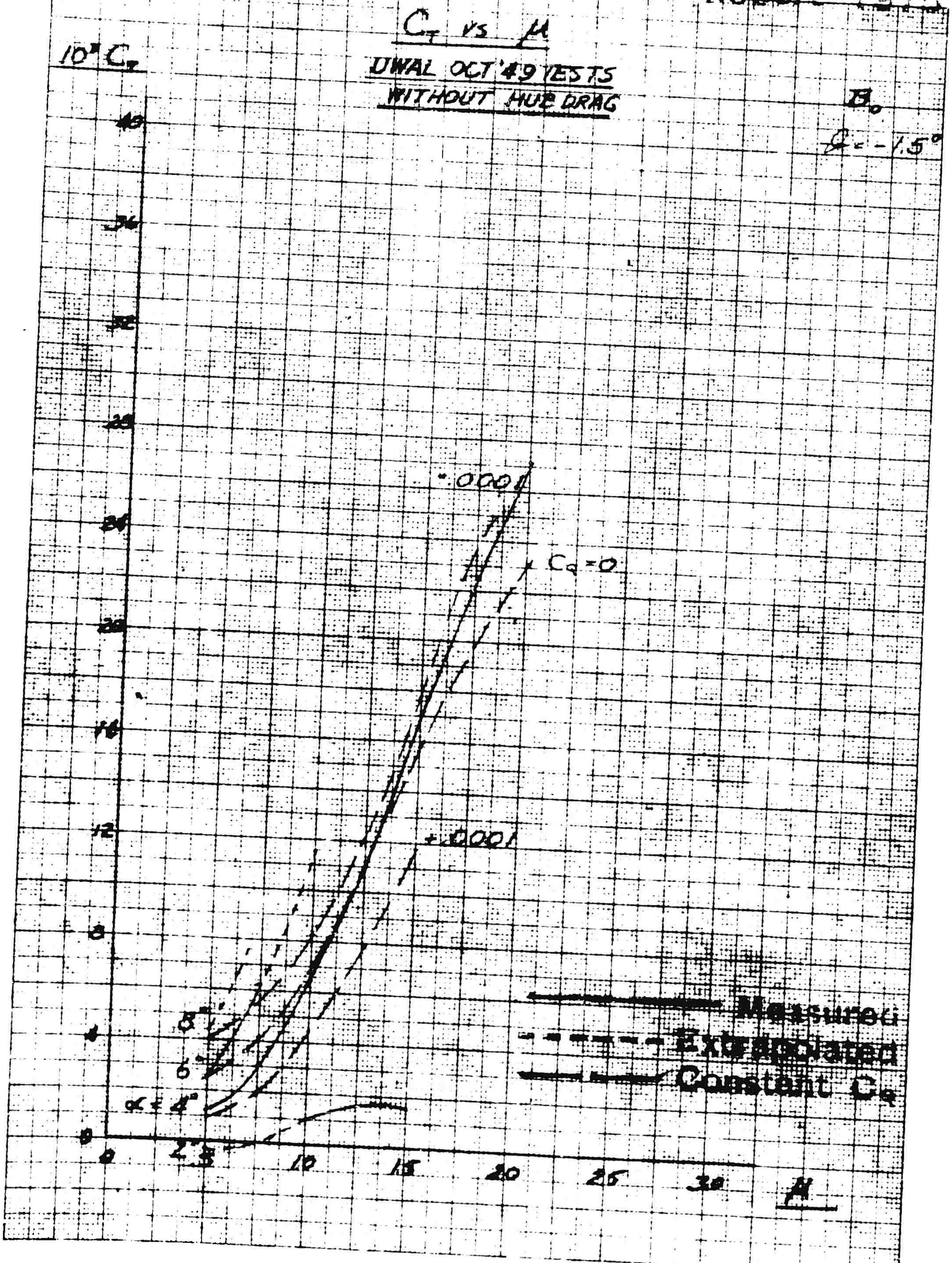
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

CONFIDENTIAL

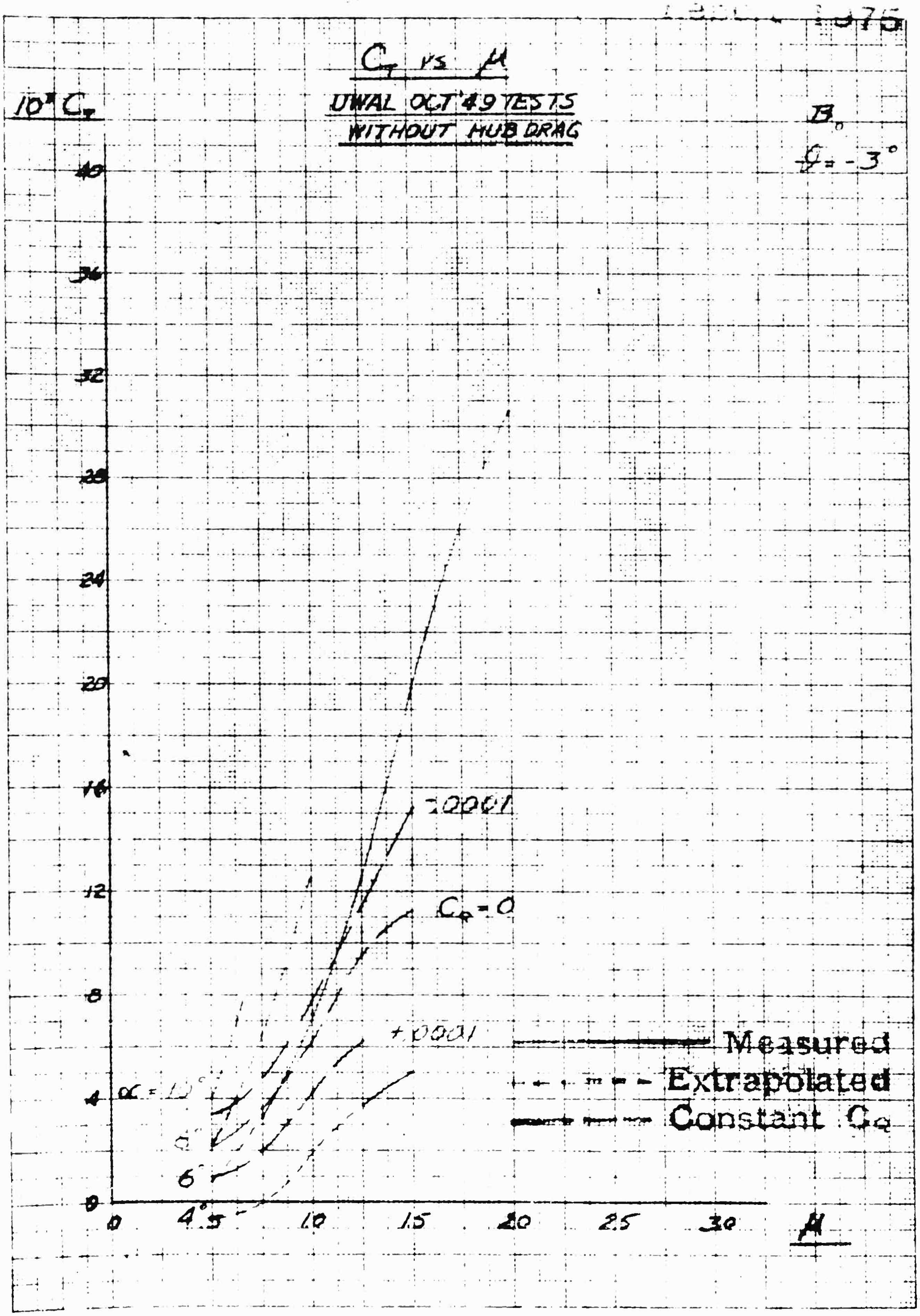


CONFIDENTIAL

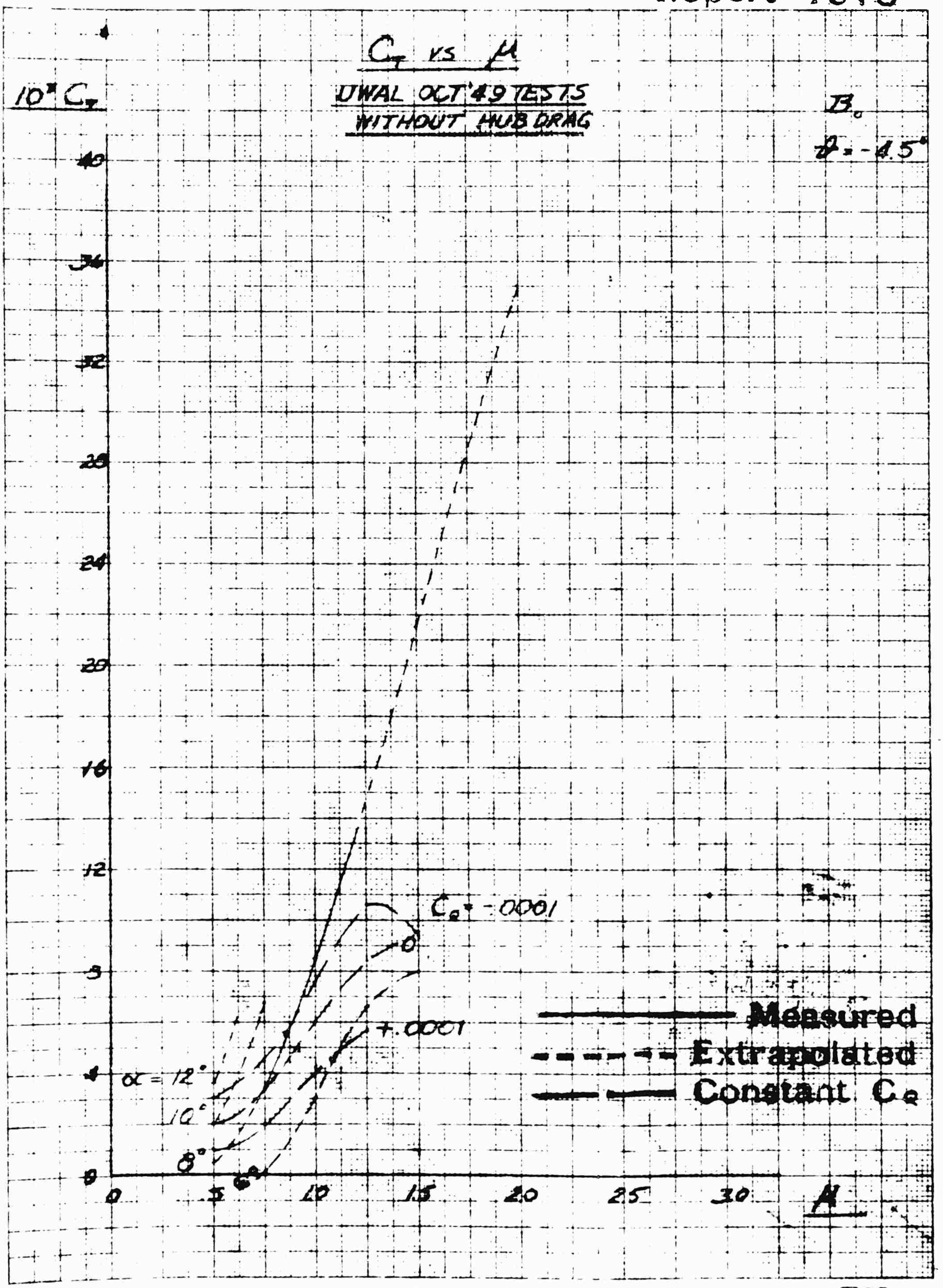
RCS
12-13-49



No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.
KEUFFEL & ESSER CO.

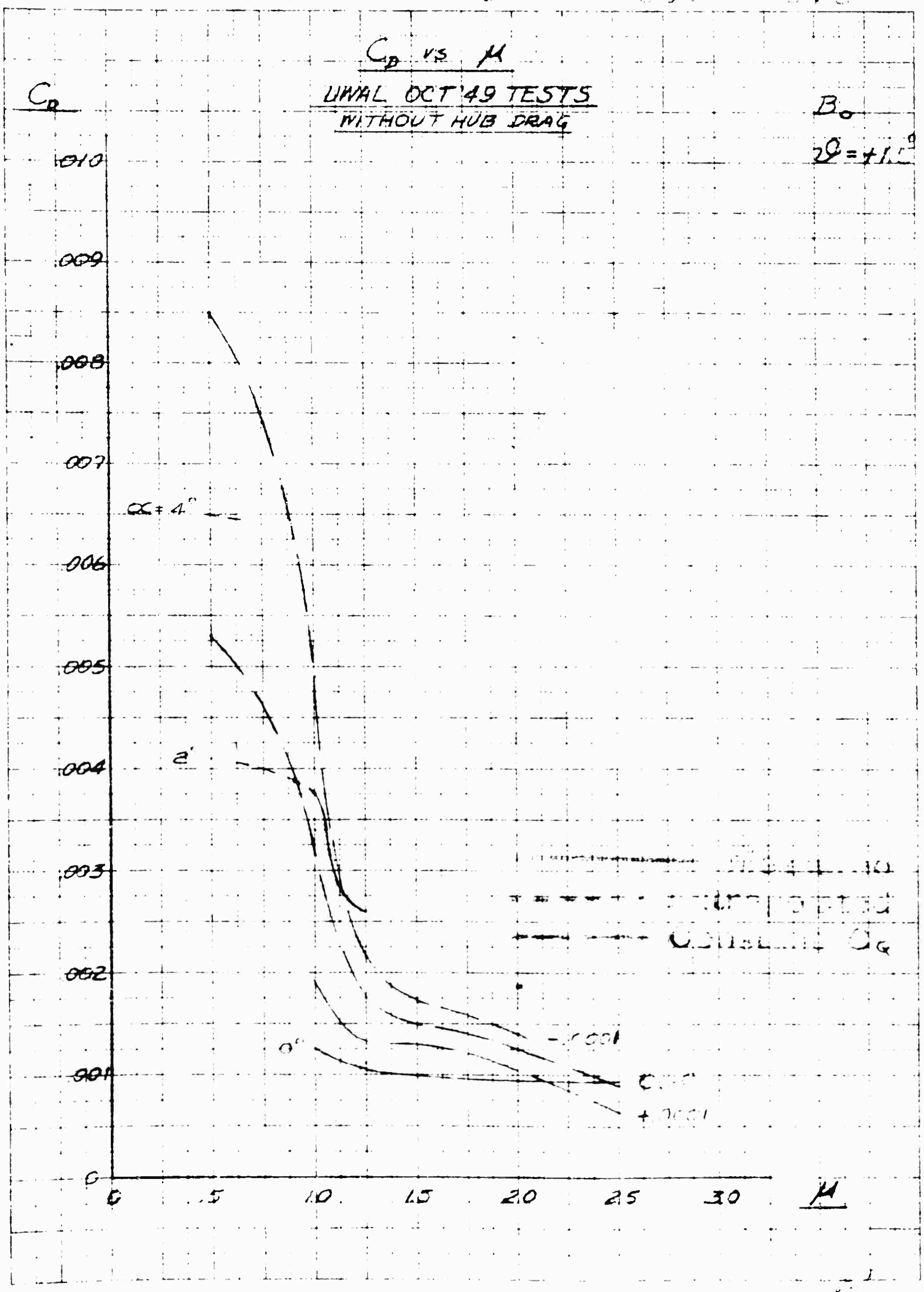


C_T vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
B_0
$\theta = -3°$
40
36
32
28
24
20
16
12
8
4
0
.0001
$C_Q = 0$
+.0001
$\alpha = 10°$
8°
6°
4°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_Q

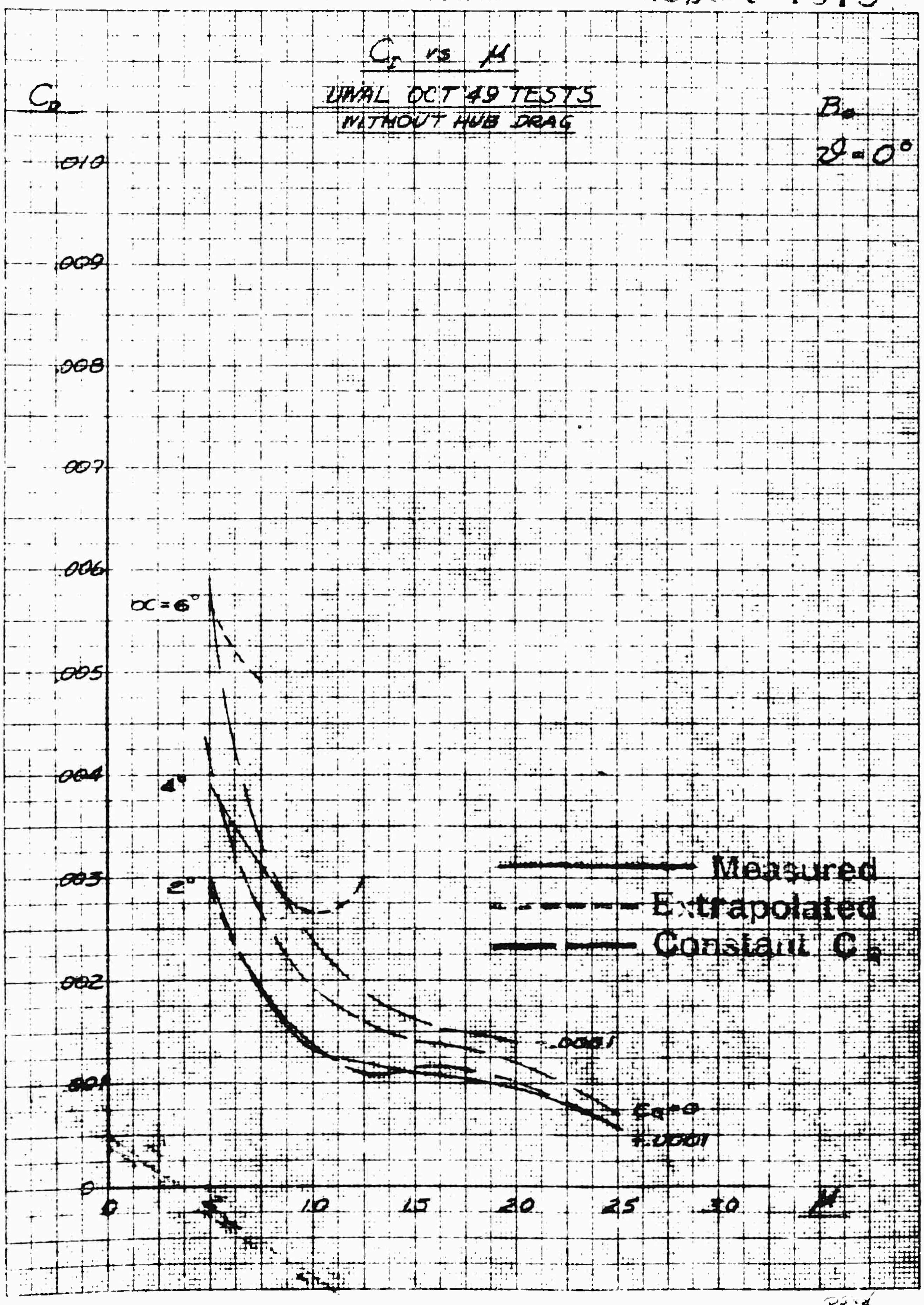

C_T vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^4 C_T$
B_o
$\theta = -4.5°$
40
36
32
28
24
20
16
12
8
4
0
$C_Q = -.0001$
0
+.0001
$\alpha = 12°$
10°
8°
6°
0
.5
.10
.15
.20
.25
.30
μ
Measured
Extrapolated
Constant C_Q

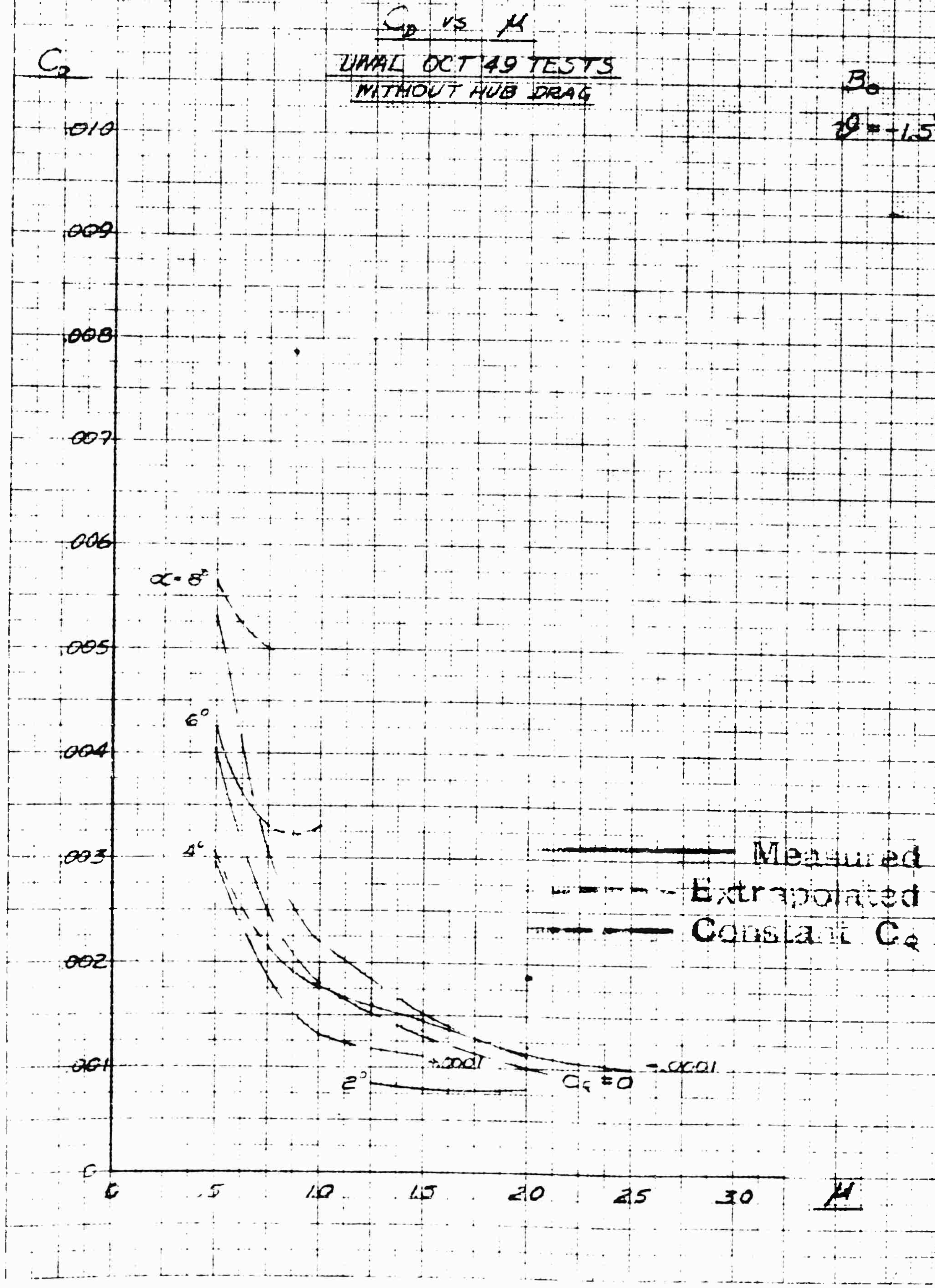
RCS
12-13-49

KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy

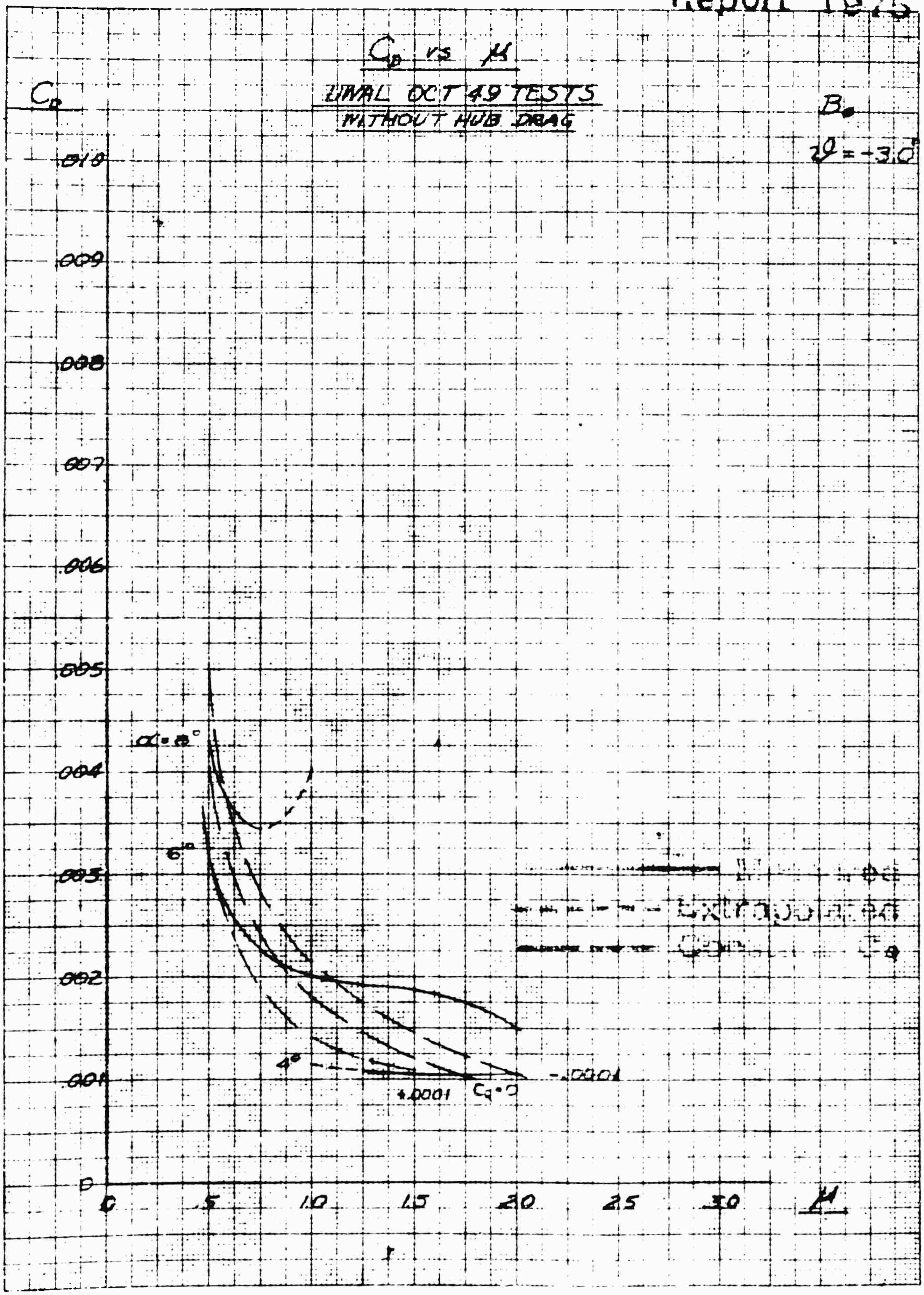


C_D vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
C_D
B_0
$\theta = +1.5°$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 4°$
2°
0°
−.0001
+.0001
0
.5
1.0
1.5
2.0
2.5
3.0
μ

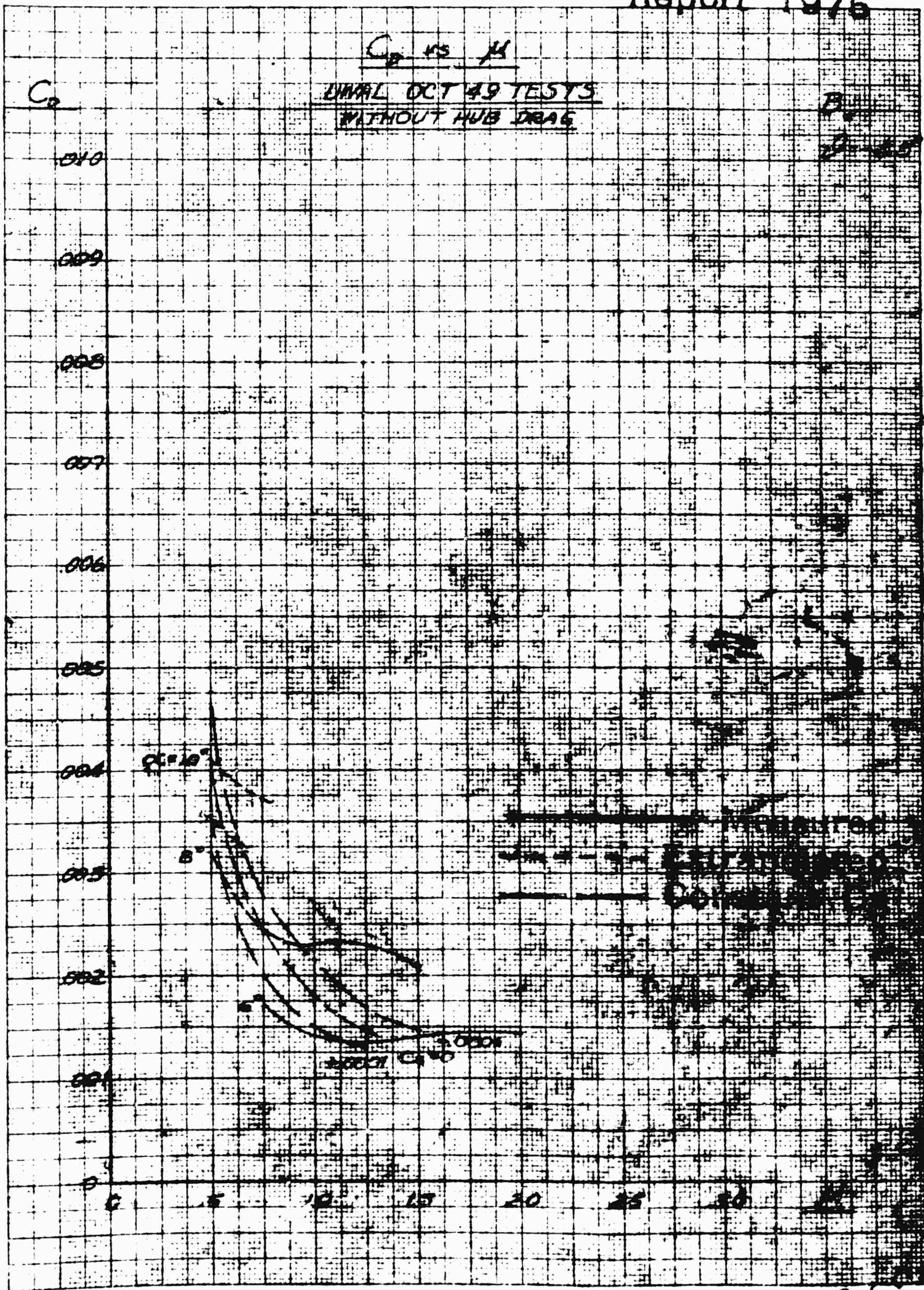

C_T vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
C_D
B_0
$\vartheta = 0°$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 6°$
4°
2°
Measured
Extrapolated
Constant C_L
.0001
$C_L = 0$
.0001
0
.5
1.0
1.5
2.0
2.5
3.0
μ


C_D vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\theta = -1.5°$
C_D
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
$\alpha = 8°$
6°
4°
2°
+.0001
-.0001
$C_Q = 0$
Measured
Extrapolated
Constant C_Q
0
.5
1.0
1.5
2.0
2.5
3.0
μ

CONFIDENTIAL



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

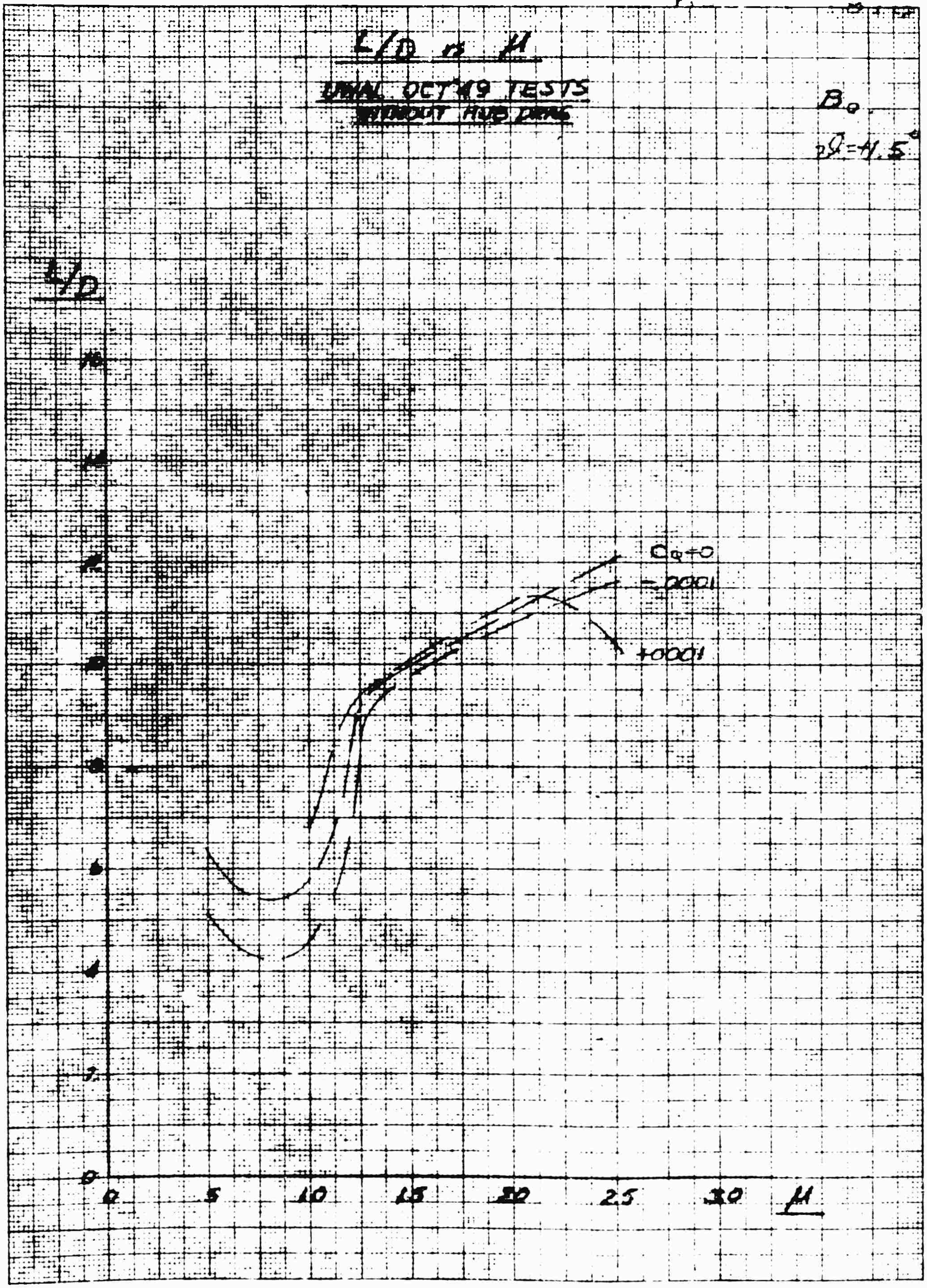


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENT

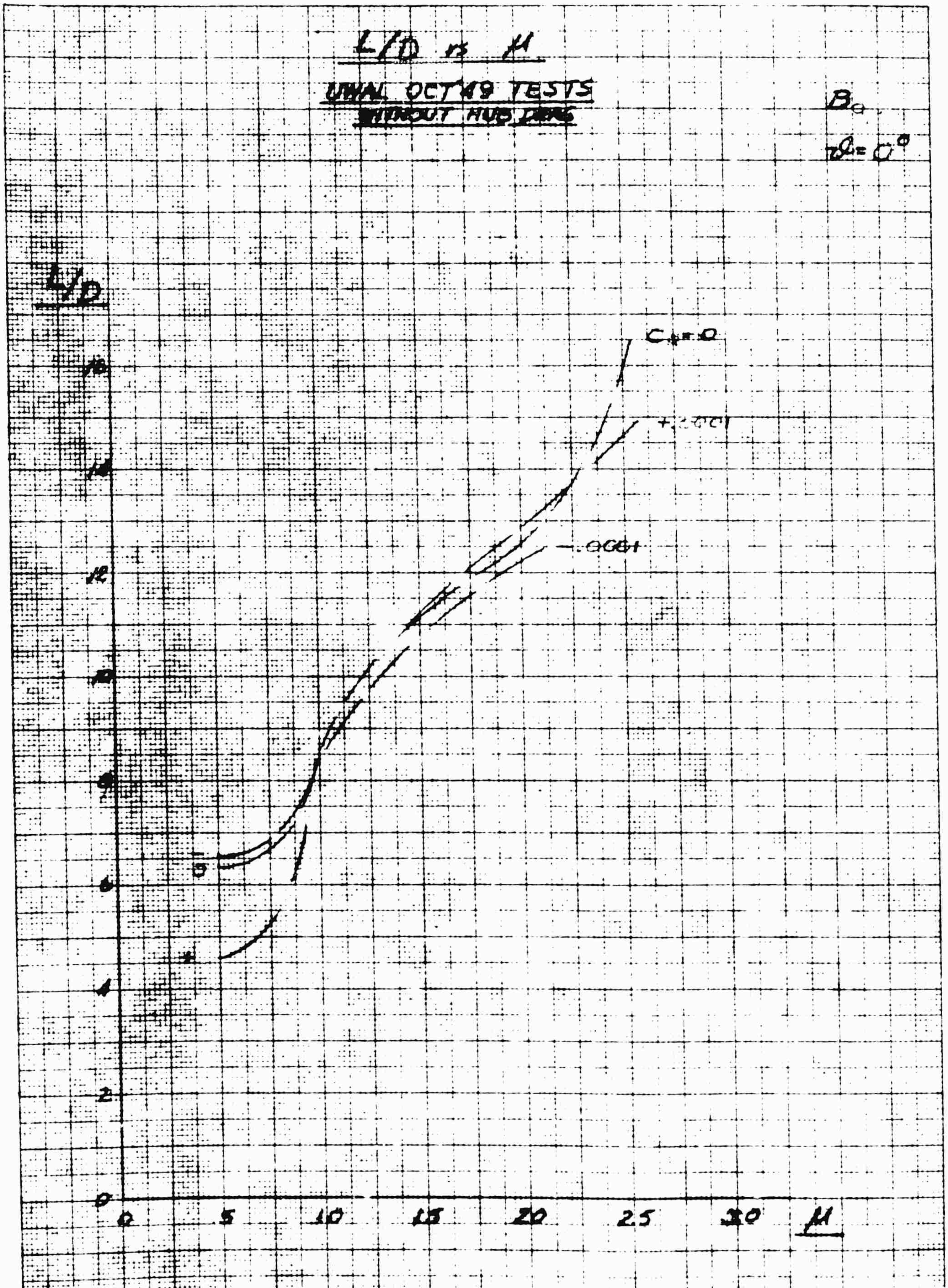
12-13-49

CONFIDENTIAL

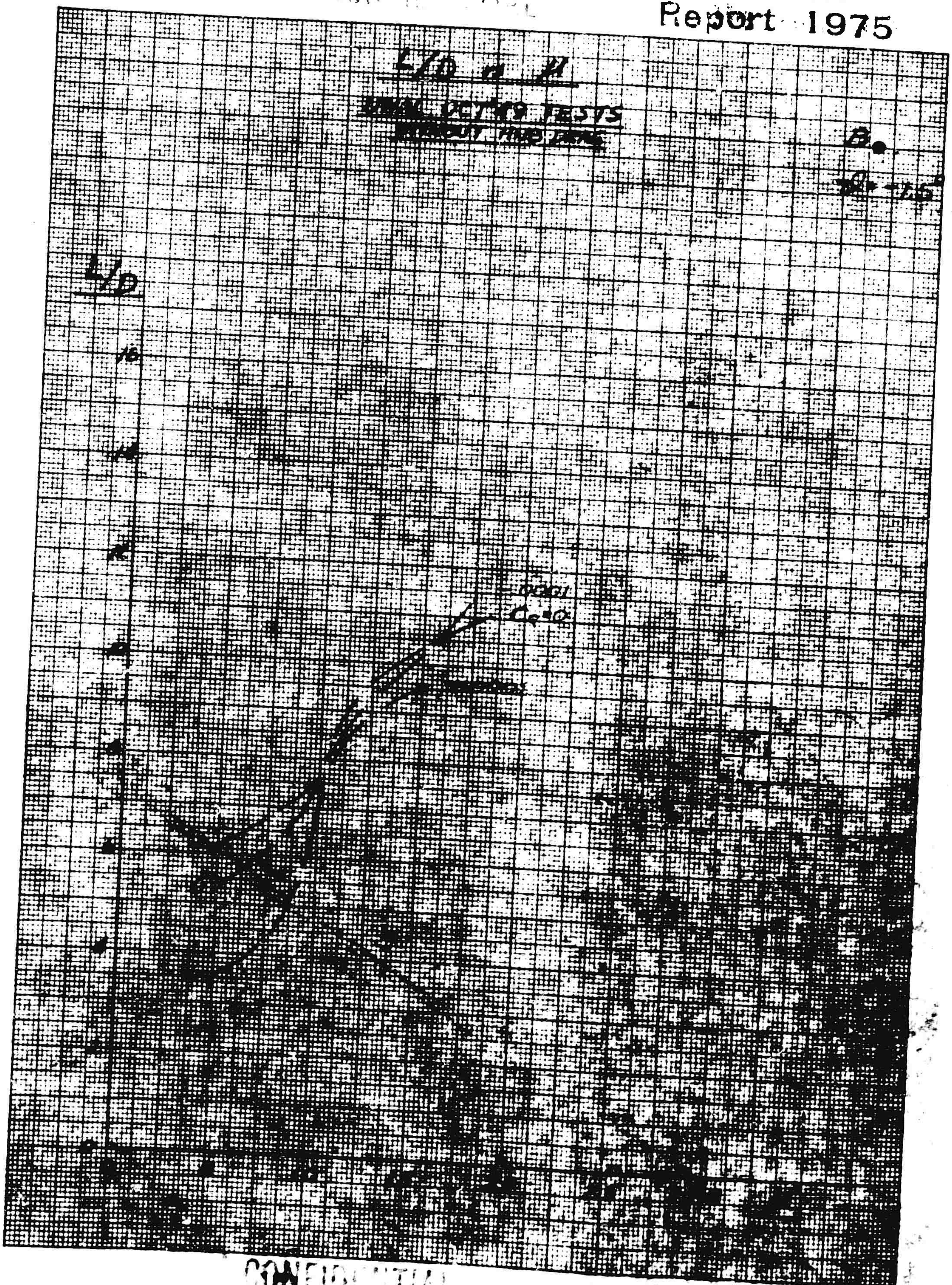


KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



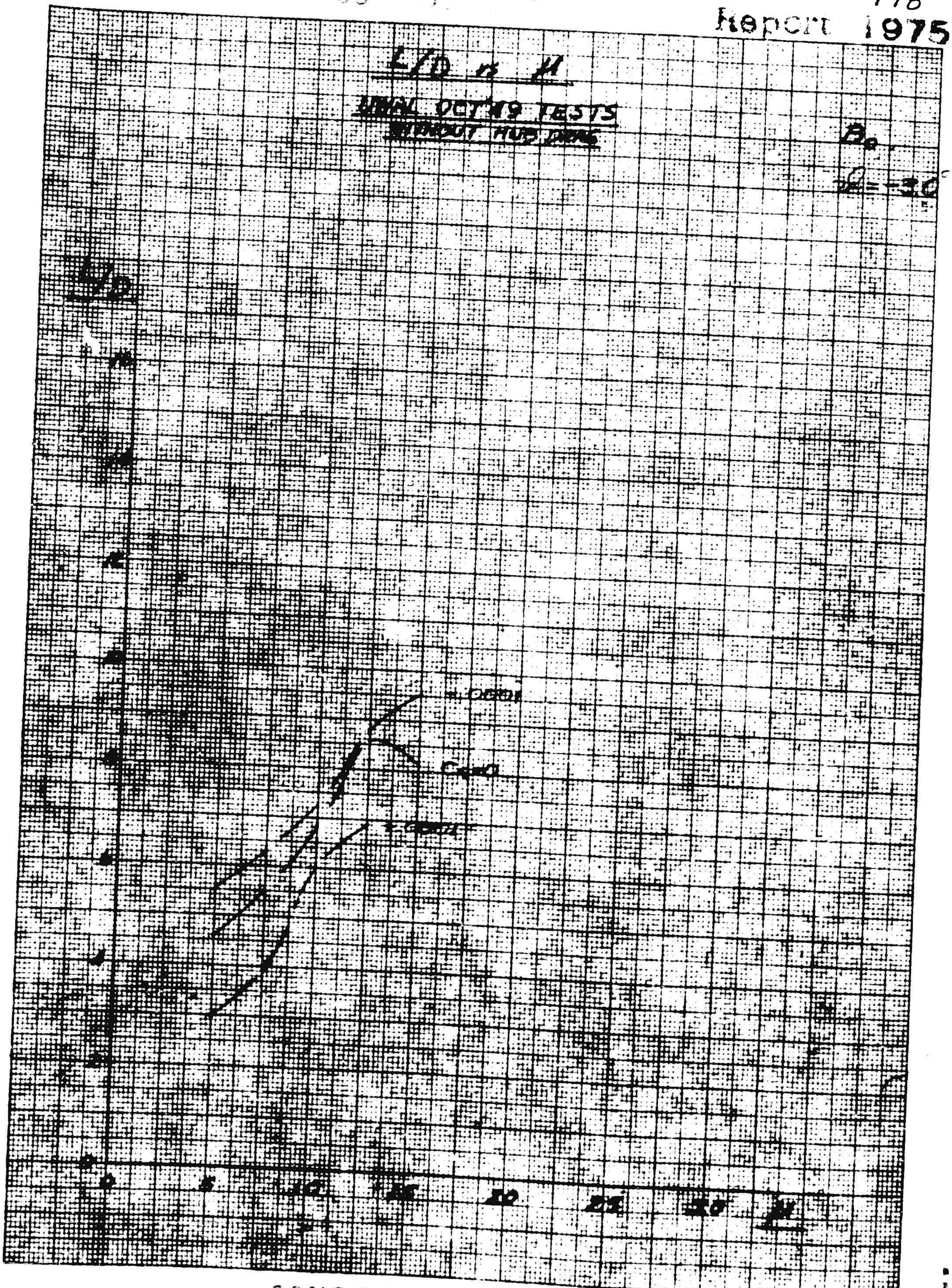
KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy



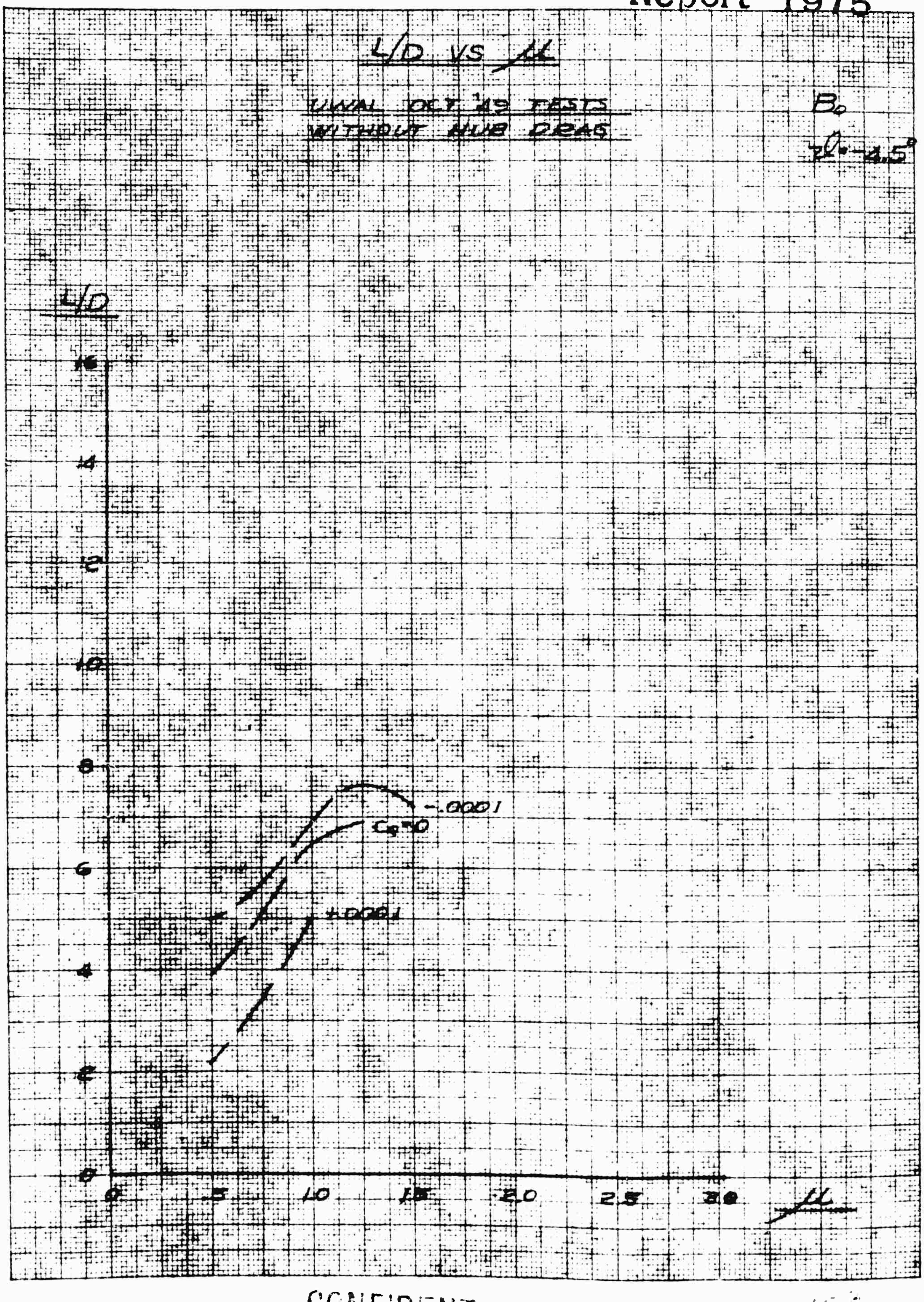
KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

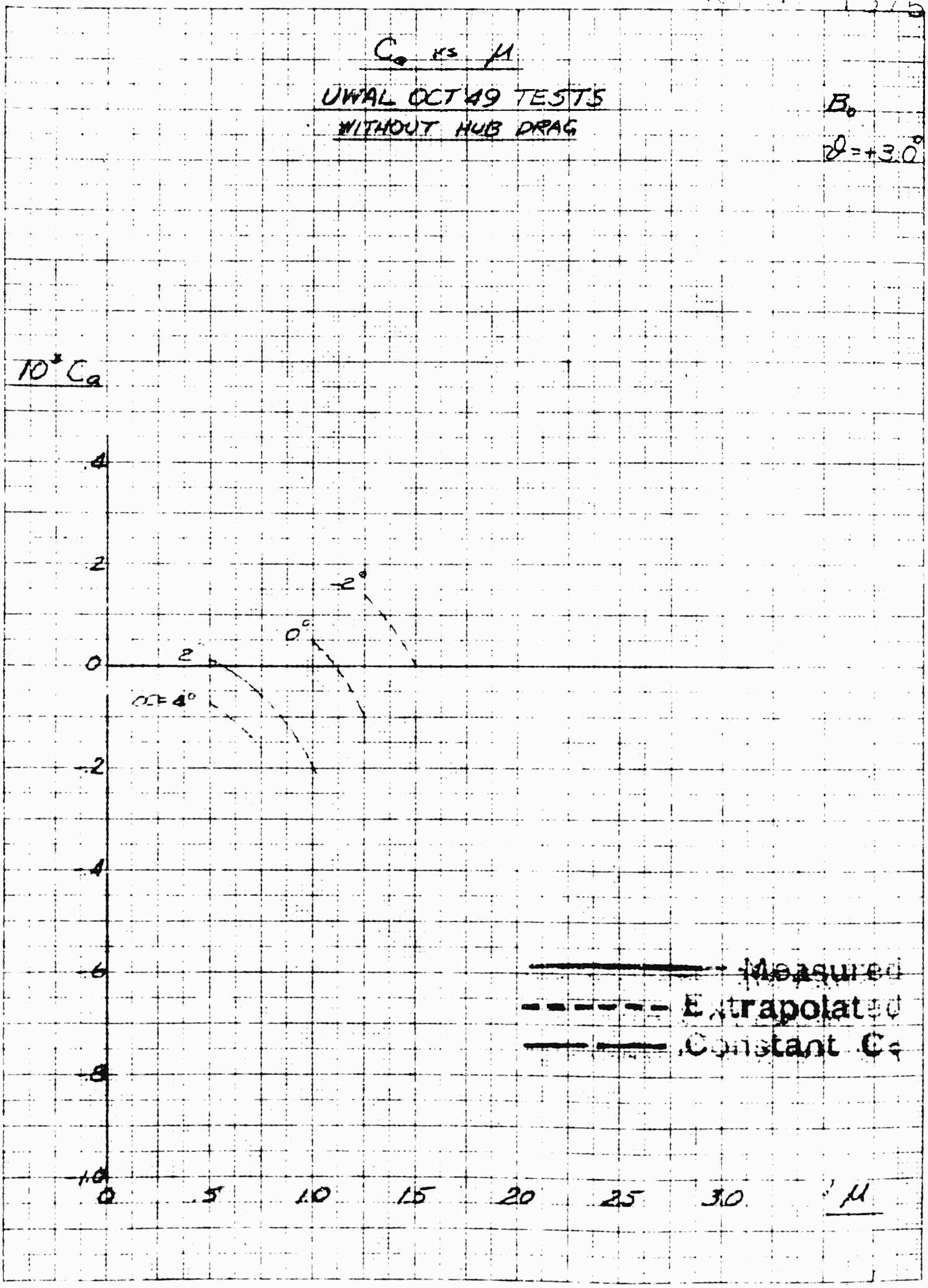


KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy
CONFIDENTIAL

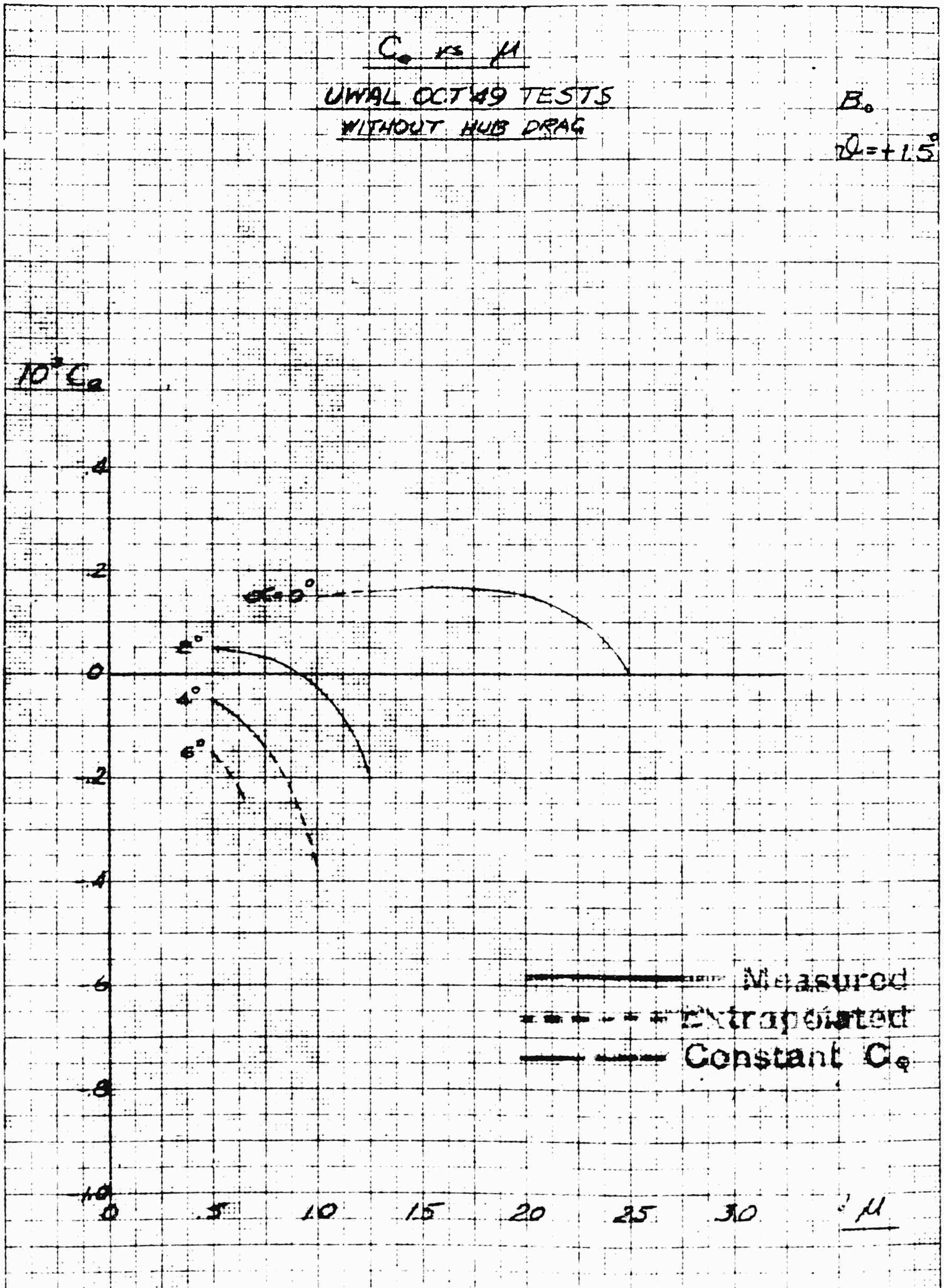


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

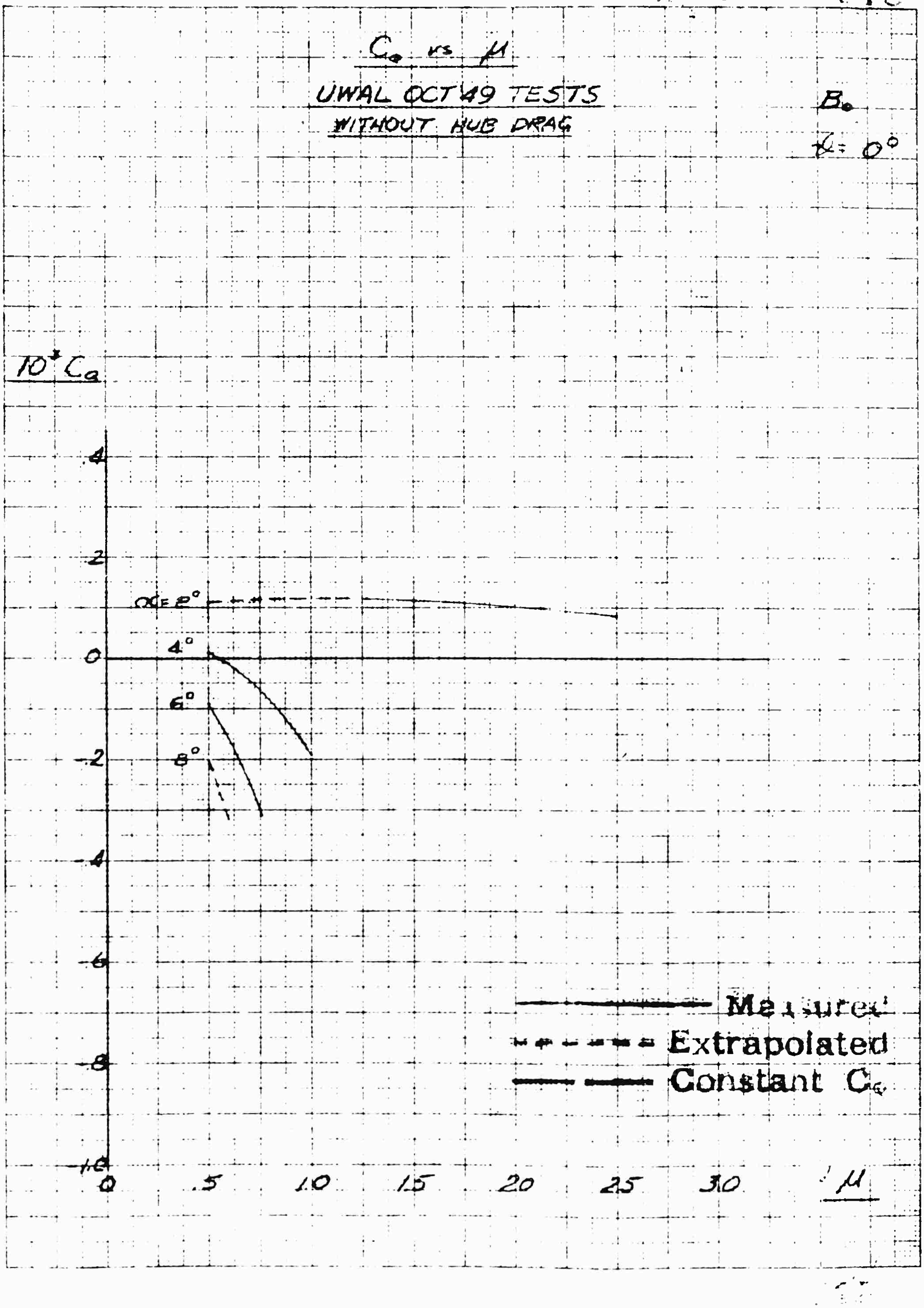
180

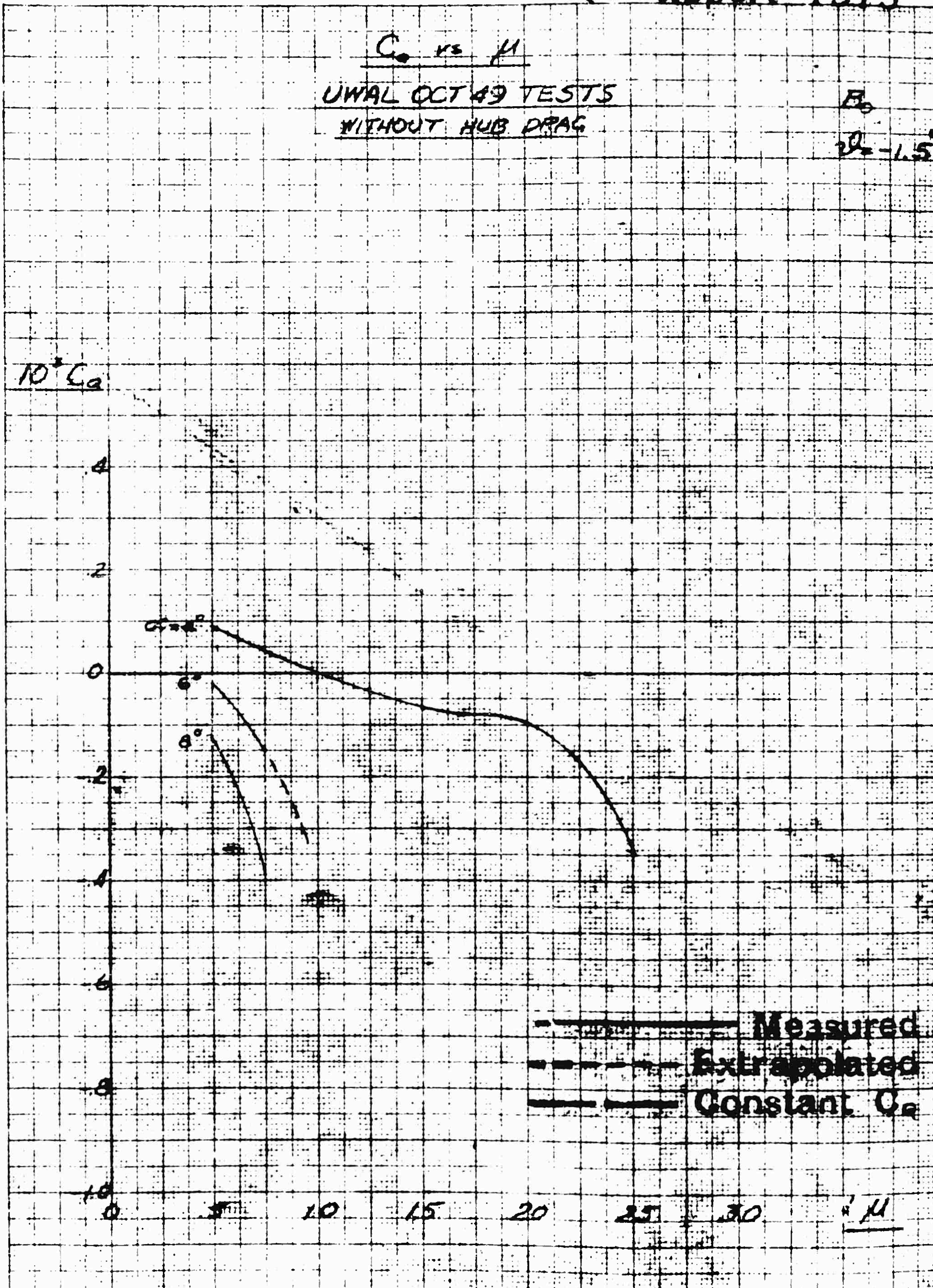


C_a vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B_o
$\theta = +3.0°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-2°
0°
2
α = 4°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_q



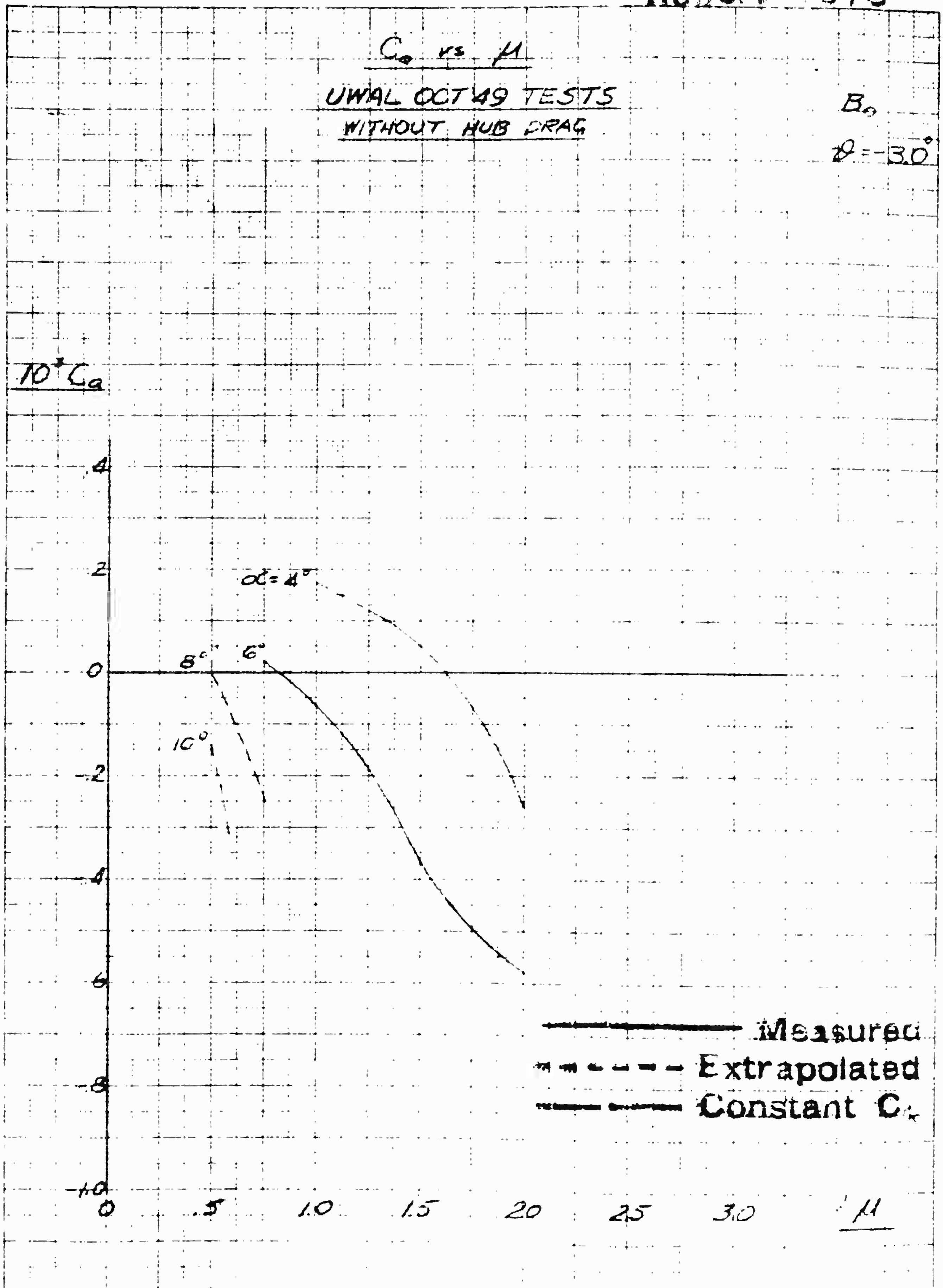
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

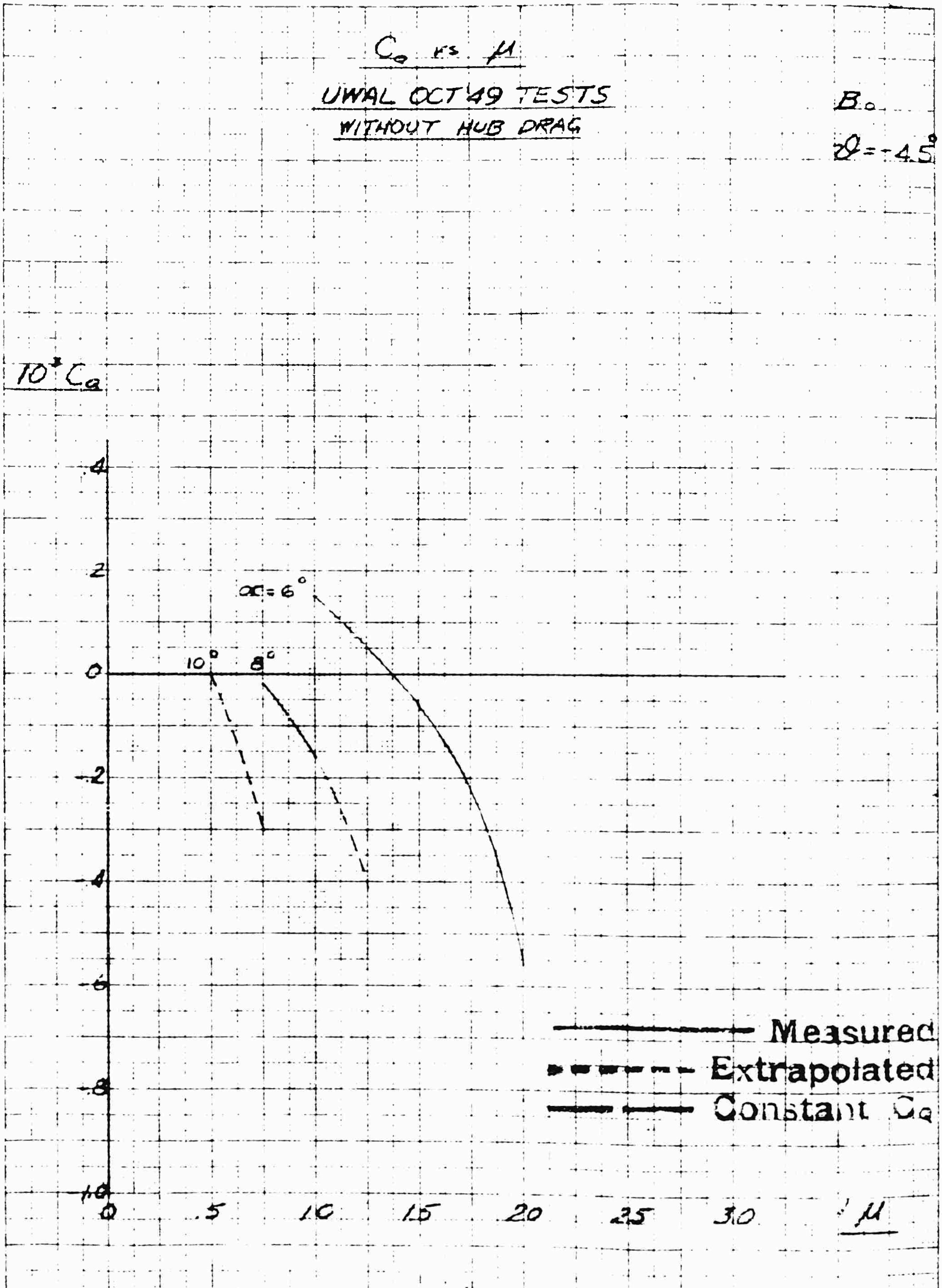

C_Q vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\delta = 0°$
$10^3 C_Q$
$\alpha_F = 2°$
4°
6°
8°
4
2
0
-2
-4
-6
-8
-10
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_Q



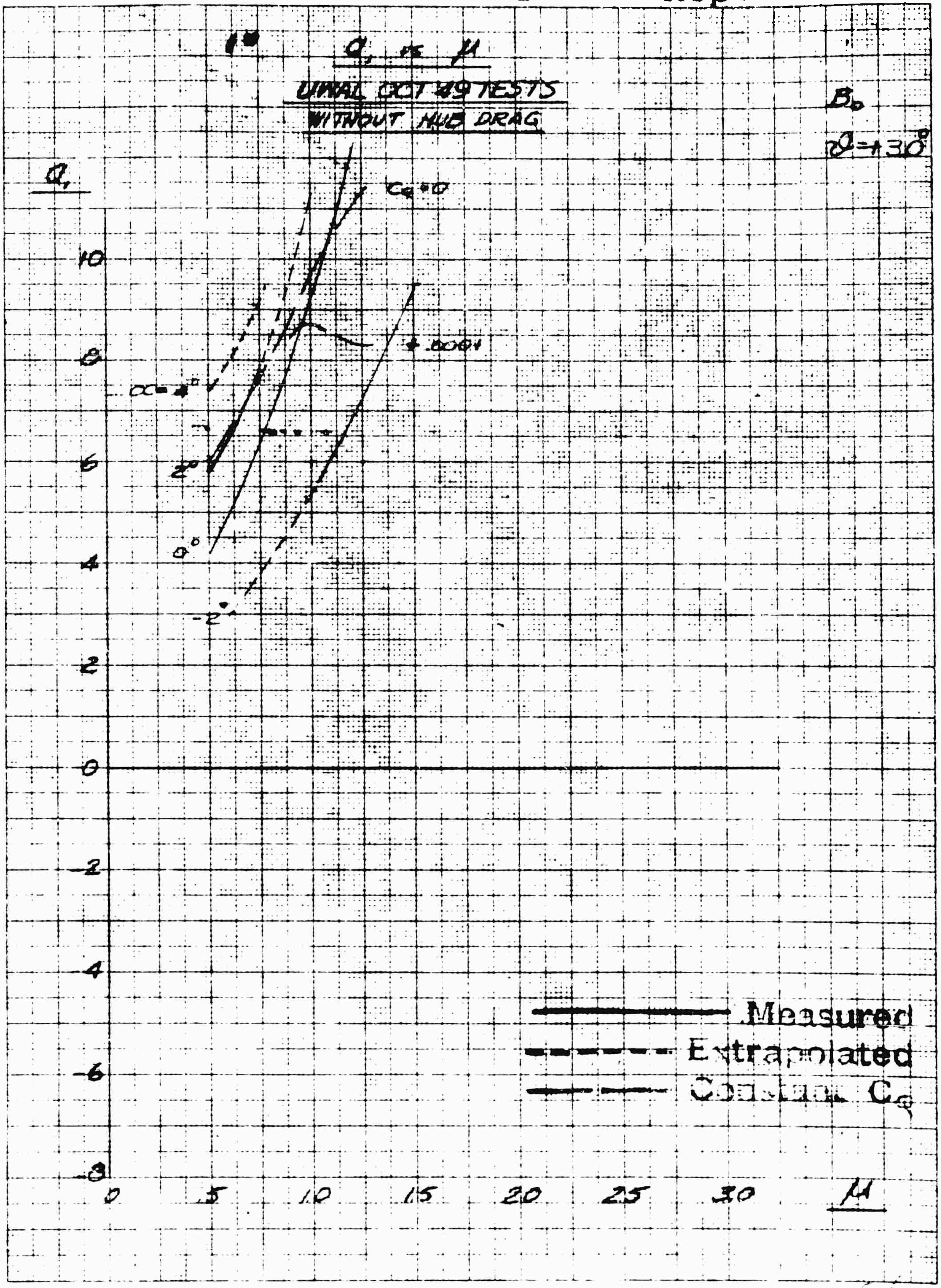
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

12-13-49


C_a vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\theta = -3.0°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
$\alpha = 4°$
6°
8°
10°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_x



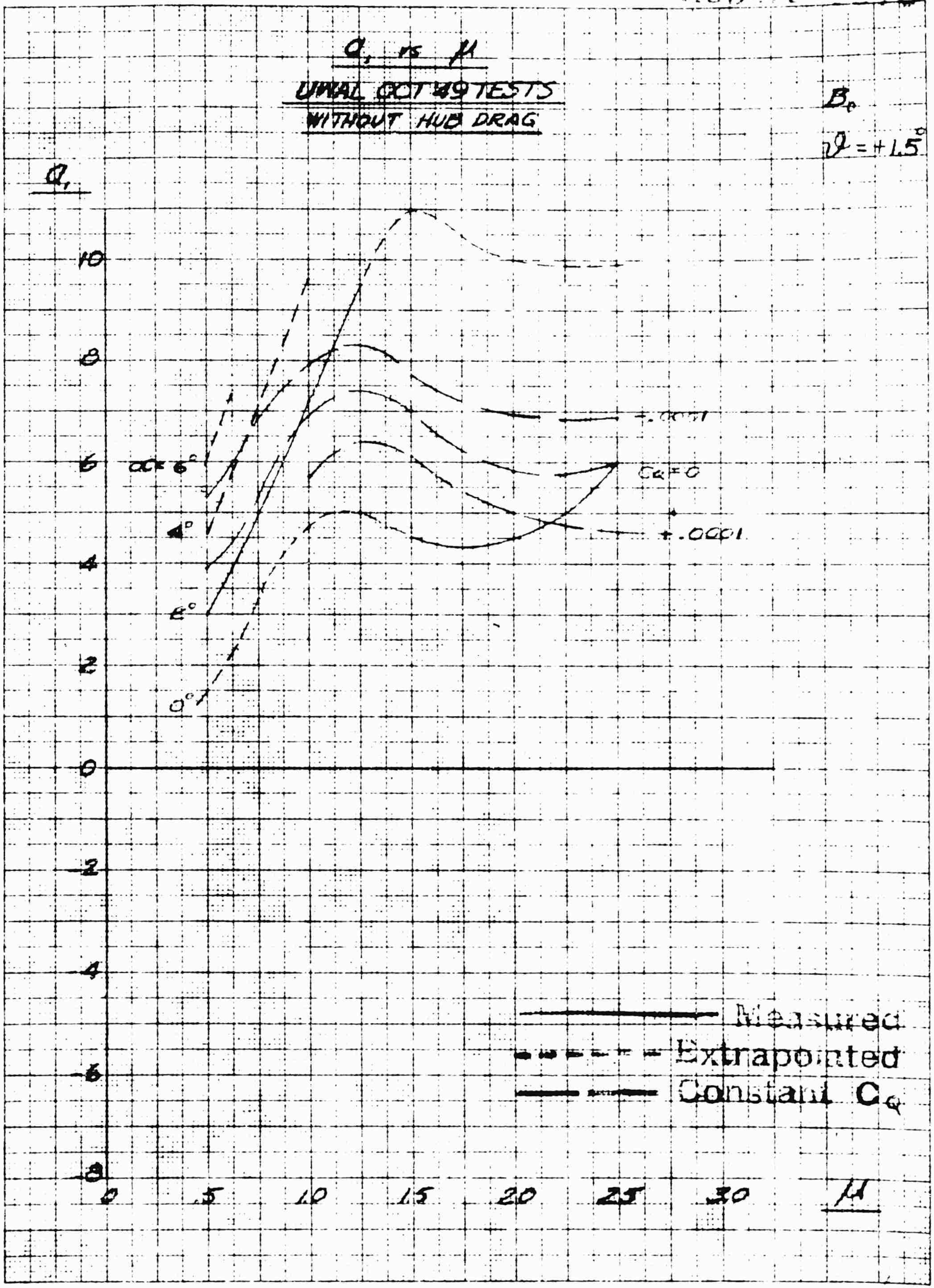
C_a vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_o
$\theta = -4.5°$
$10^3 C_a$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
$\alpha = 6°$
10°
8°
0
.5
1.0
1.5
2.0
2.5
3.0
μ
Measured
Extrapolated
Constant C_Q



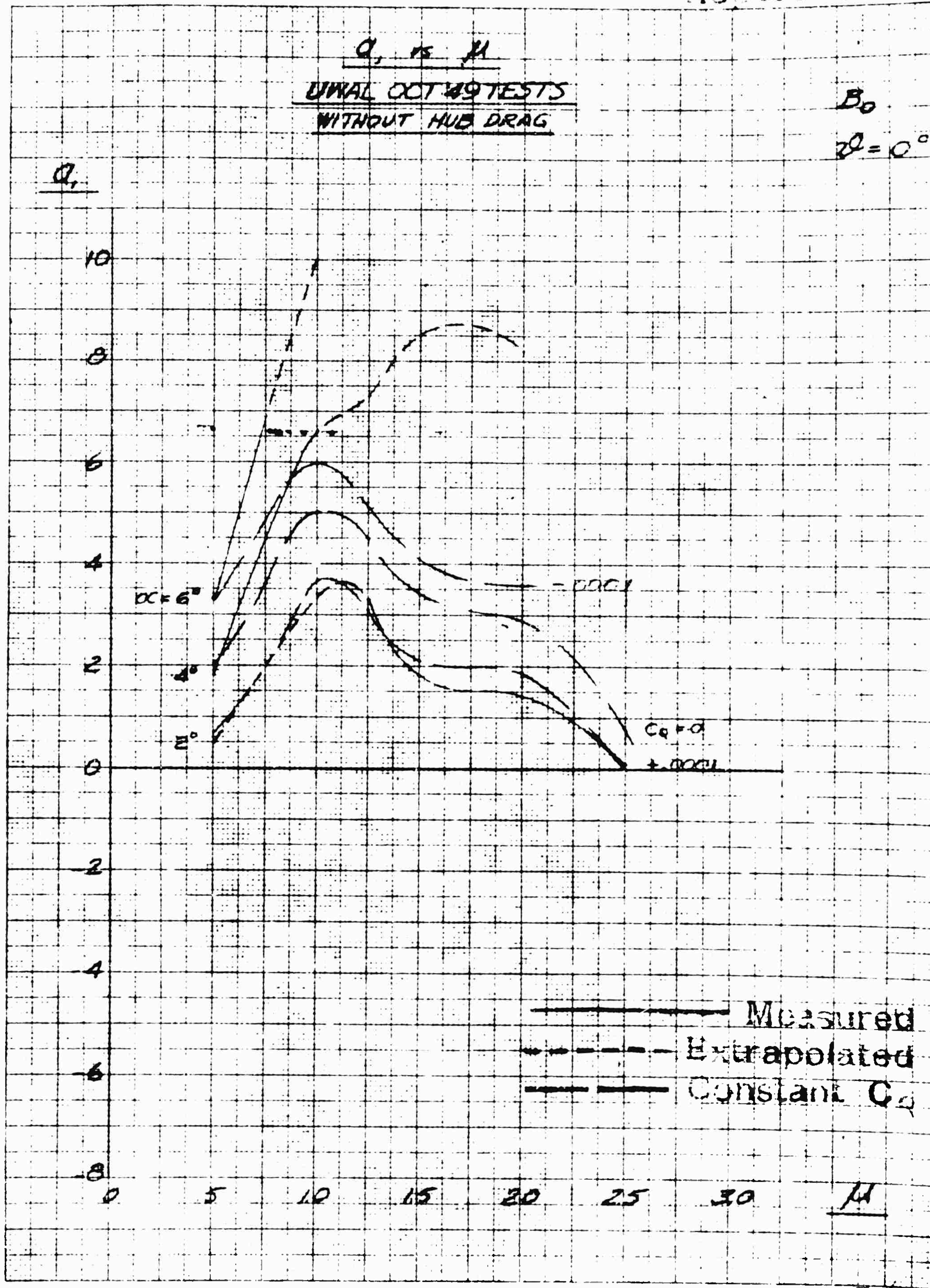
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

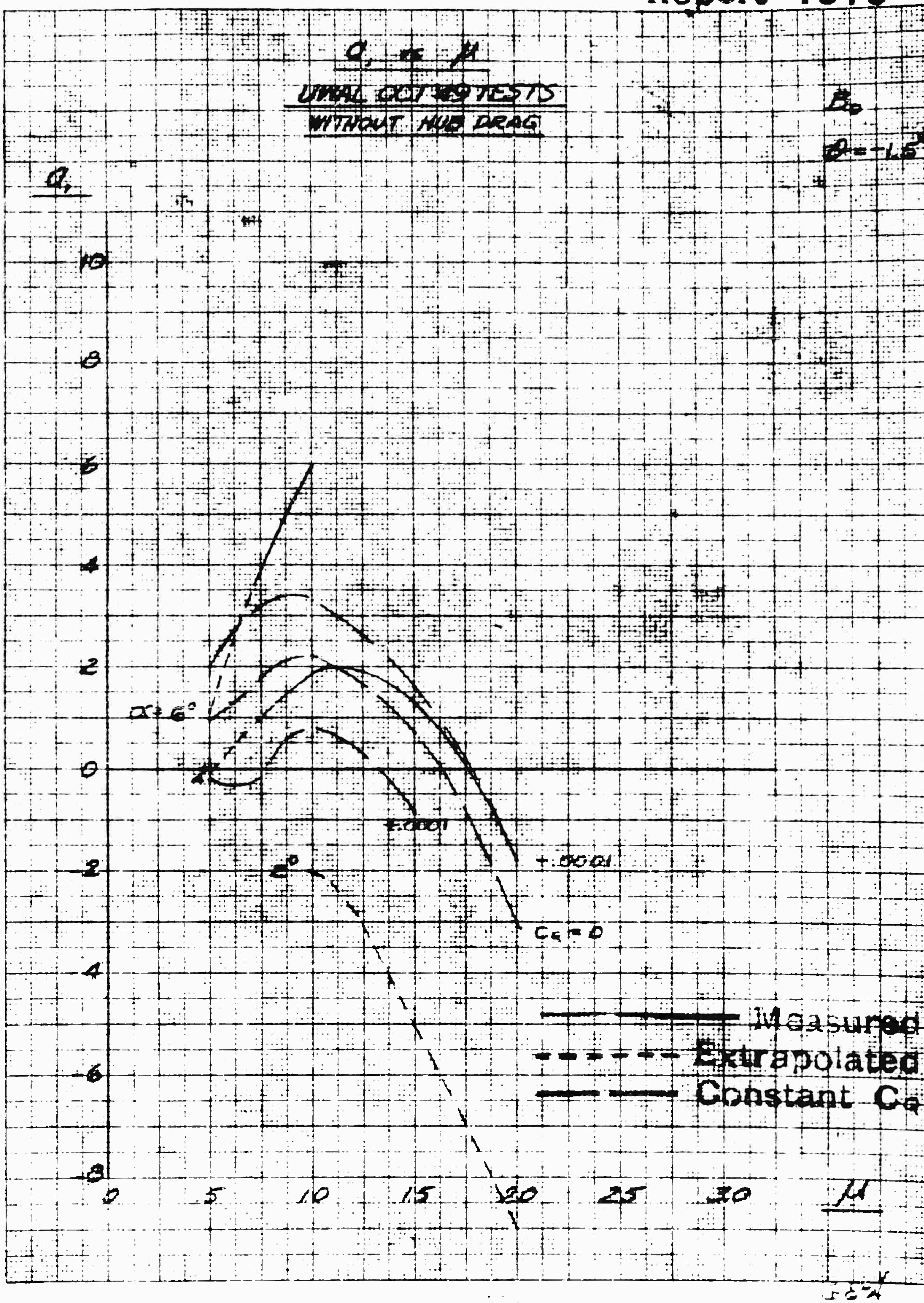
Report



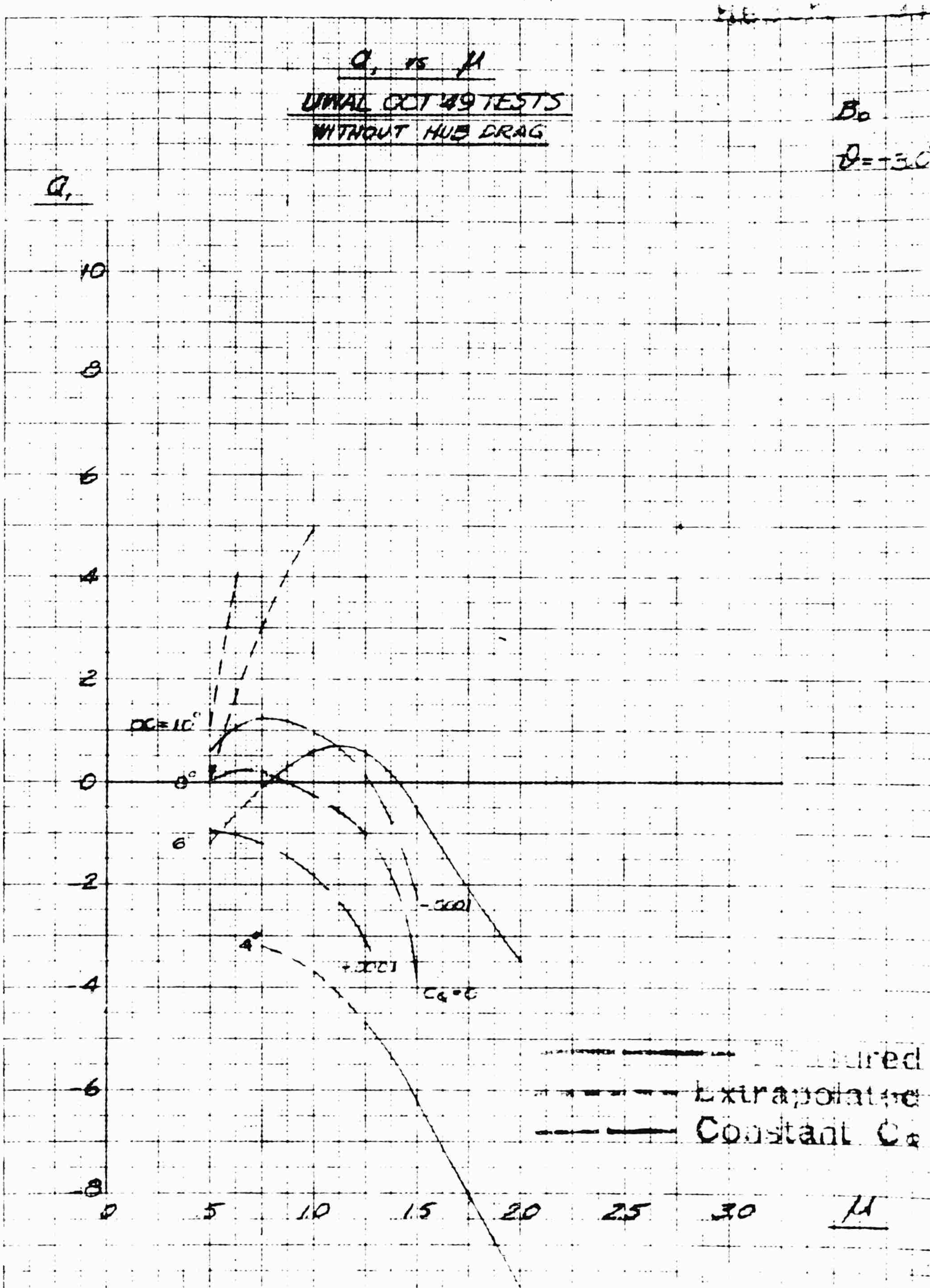
KEUFFEL & ESSER CO
No 359 14. Millimeters, 5 mm lines accented, cm lines heavy



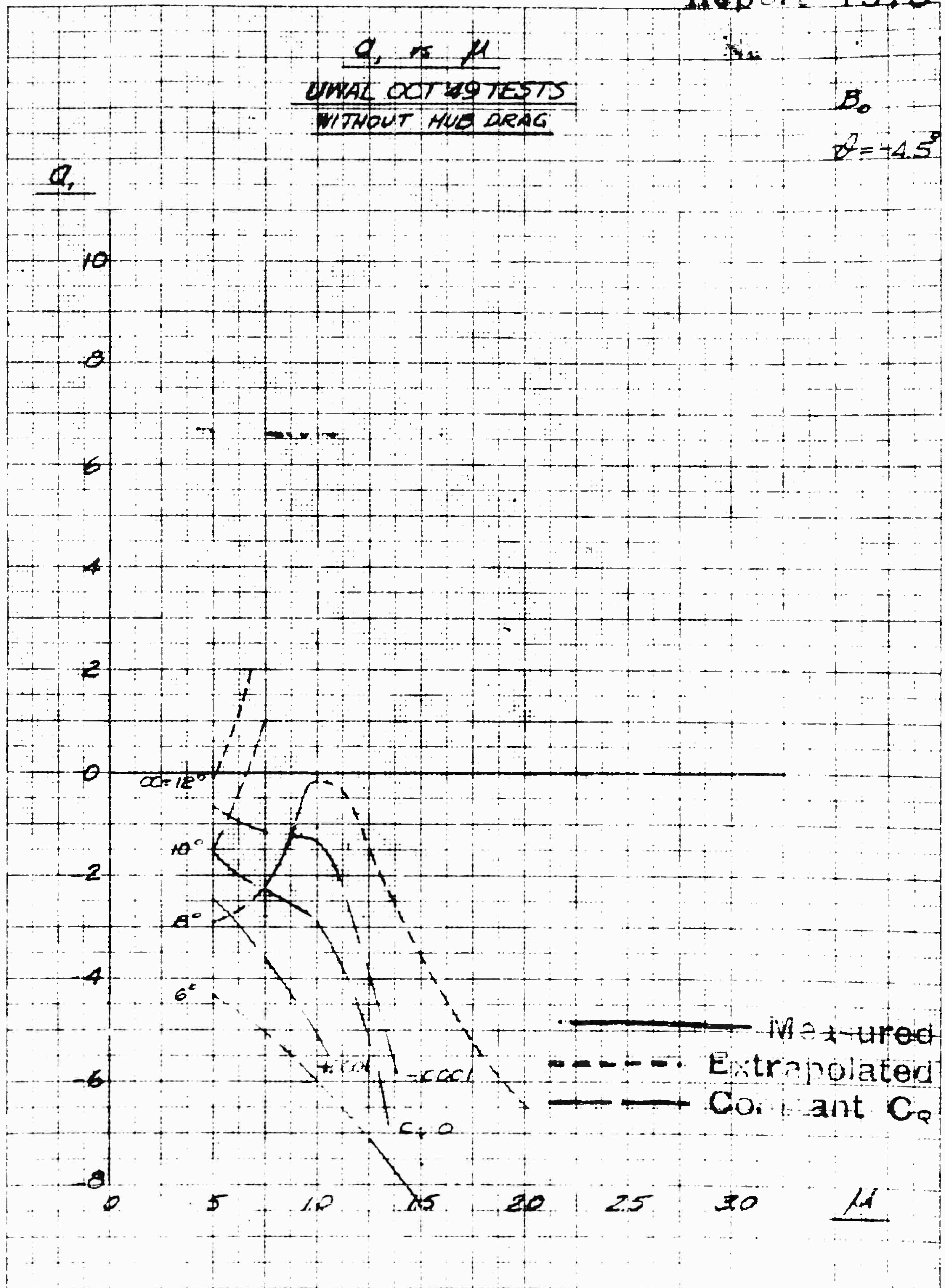
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines, accented cm lines heavy

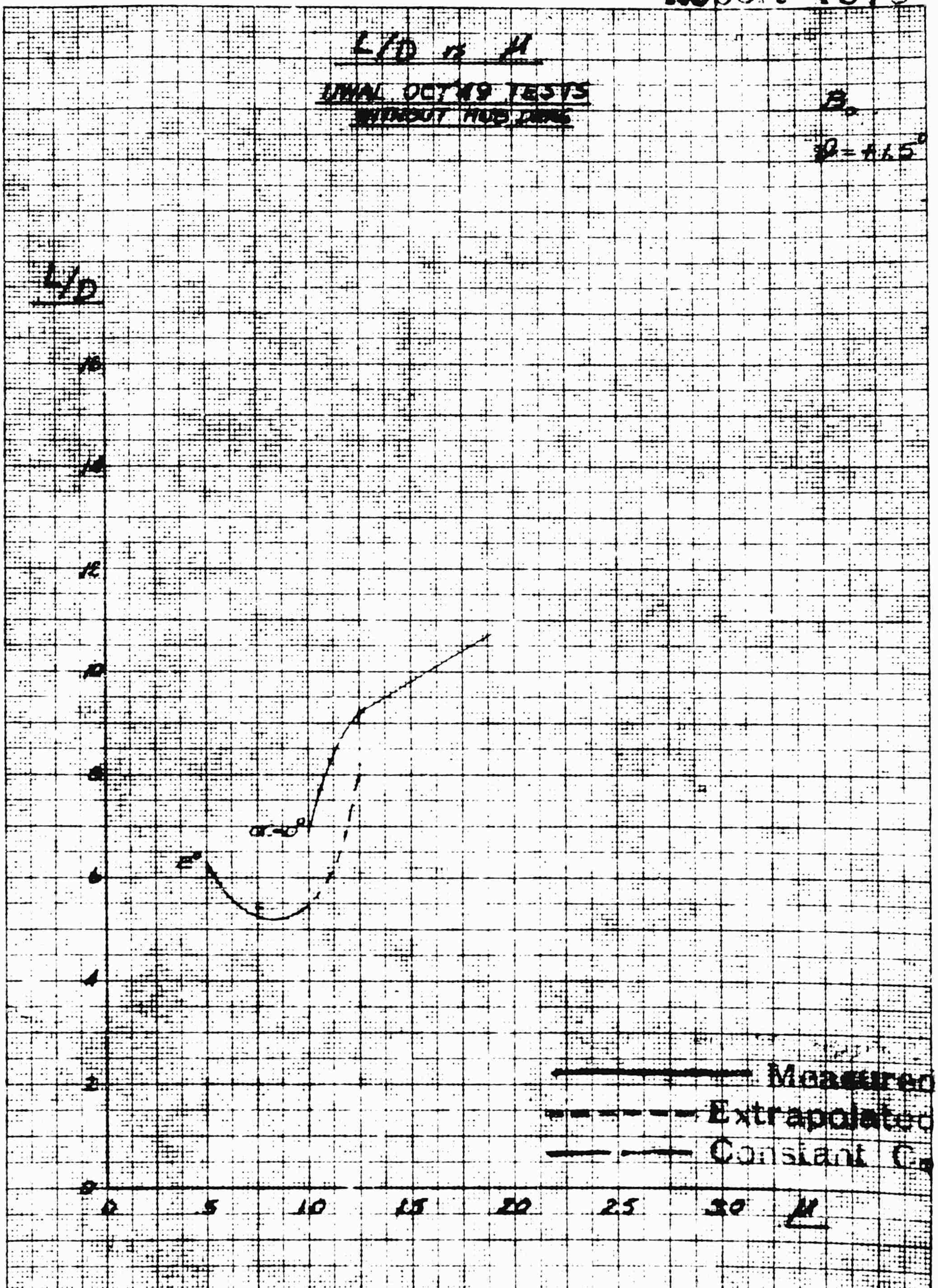


No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

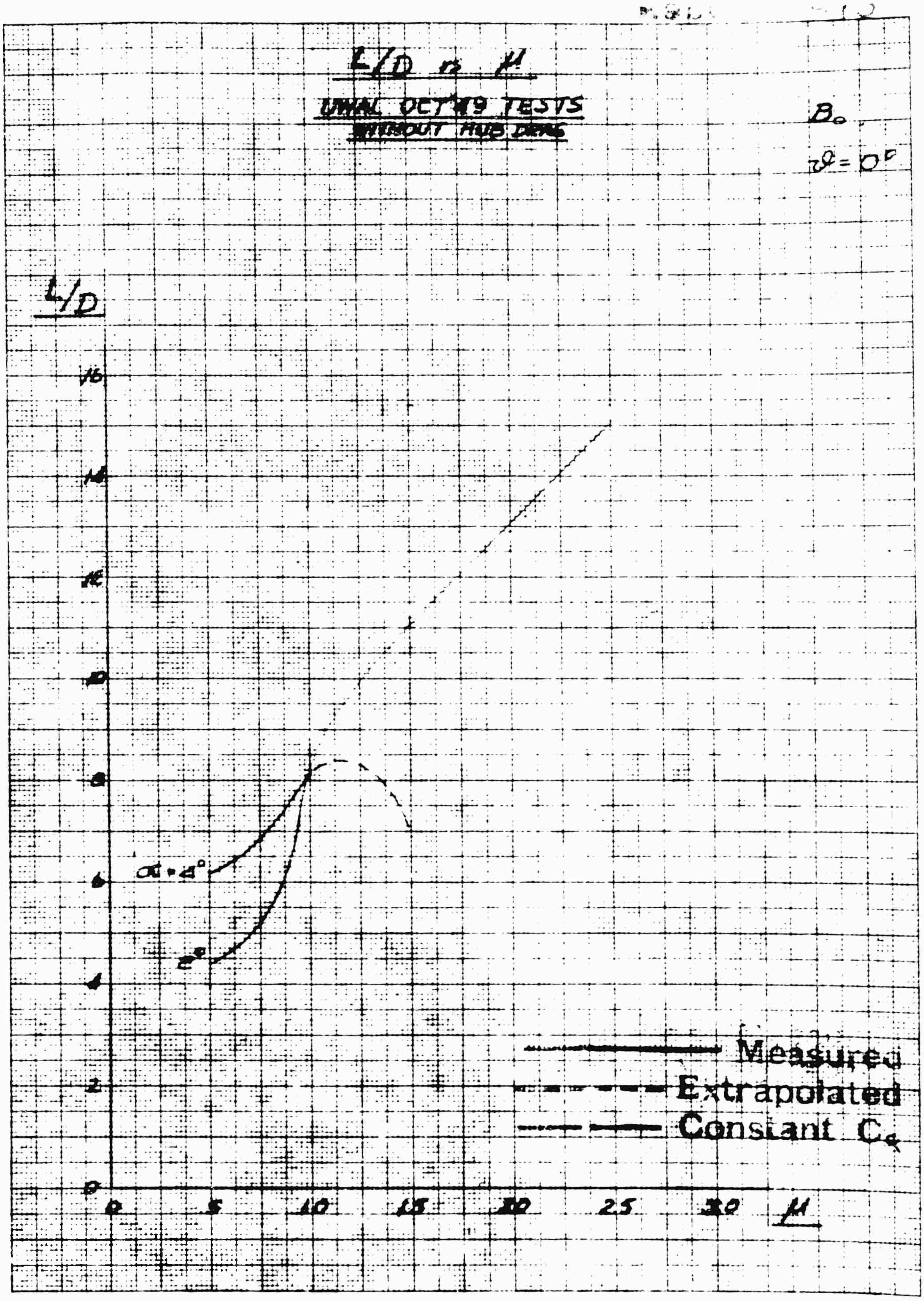


Q, vs μ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B₀
θ = -3.0°
Q,
10
8
6
4
2
0
-2
-4
-6
-8
α = 10°
8°
6°
4°
-.0001
+.0001
Cq = 0
Extrapolated
Constant Cq
0
.5
1.0
1.5
2.0
2.5
3.0
μ


Q, vs μ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B₀
θ = -4.5°
Q,
10
8
6
4
2
0
-2
-4
-6
-8
0
.5
1.0
1.5
2.0
2.5
3.0
μ
α=12°
10°
8°
6°
C_Q=0
Measured
Extrapolated
Constant C_Q

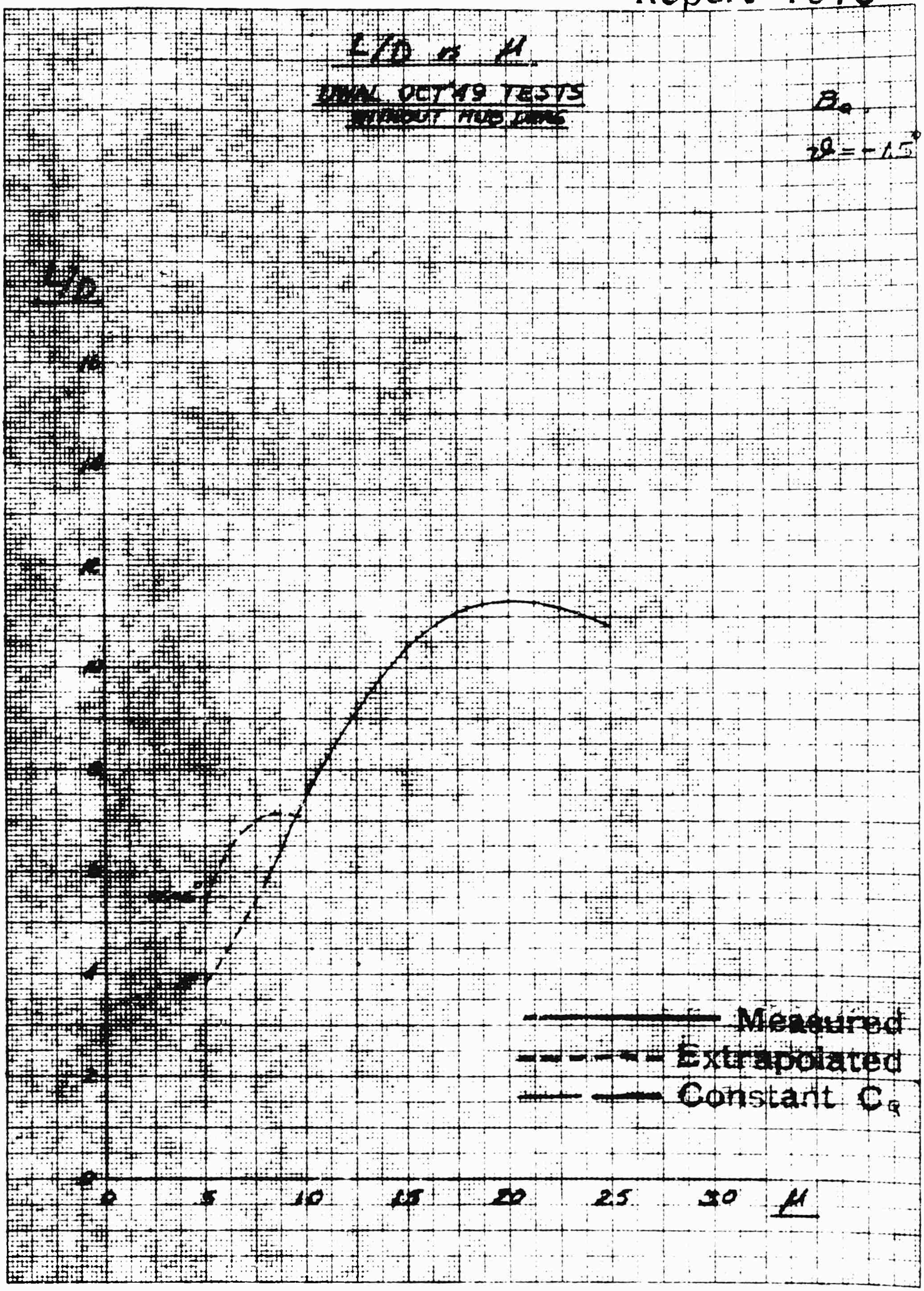


KEUFFEL & ESSER CO.
No. 1314 Millimeters, 5 mm lines accented, cm lines heavy

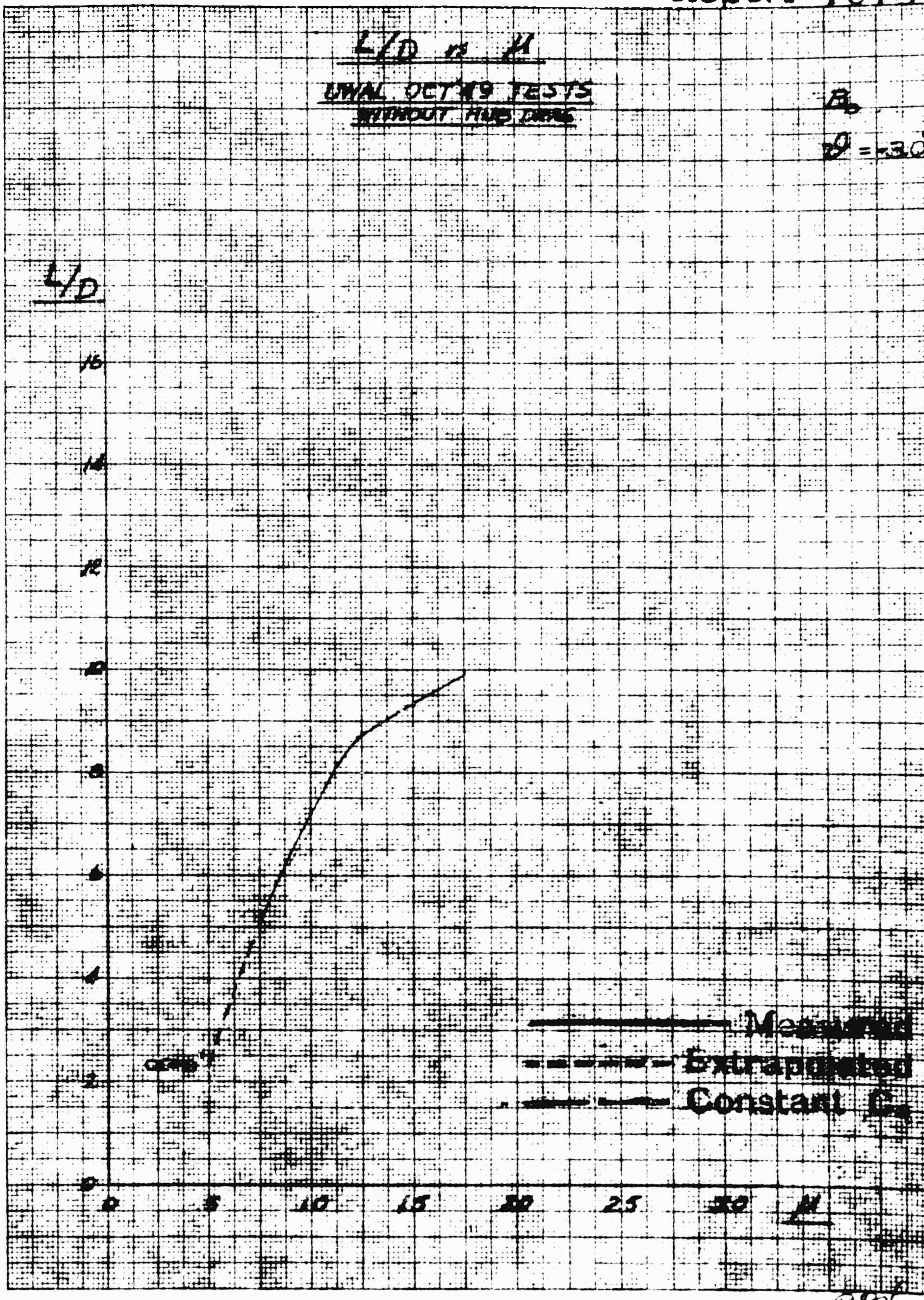


KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

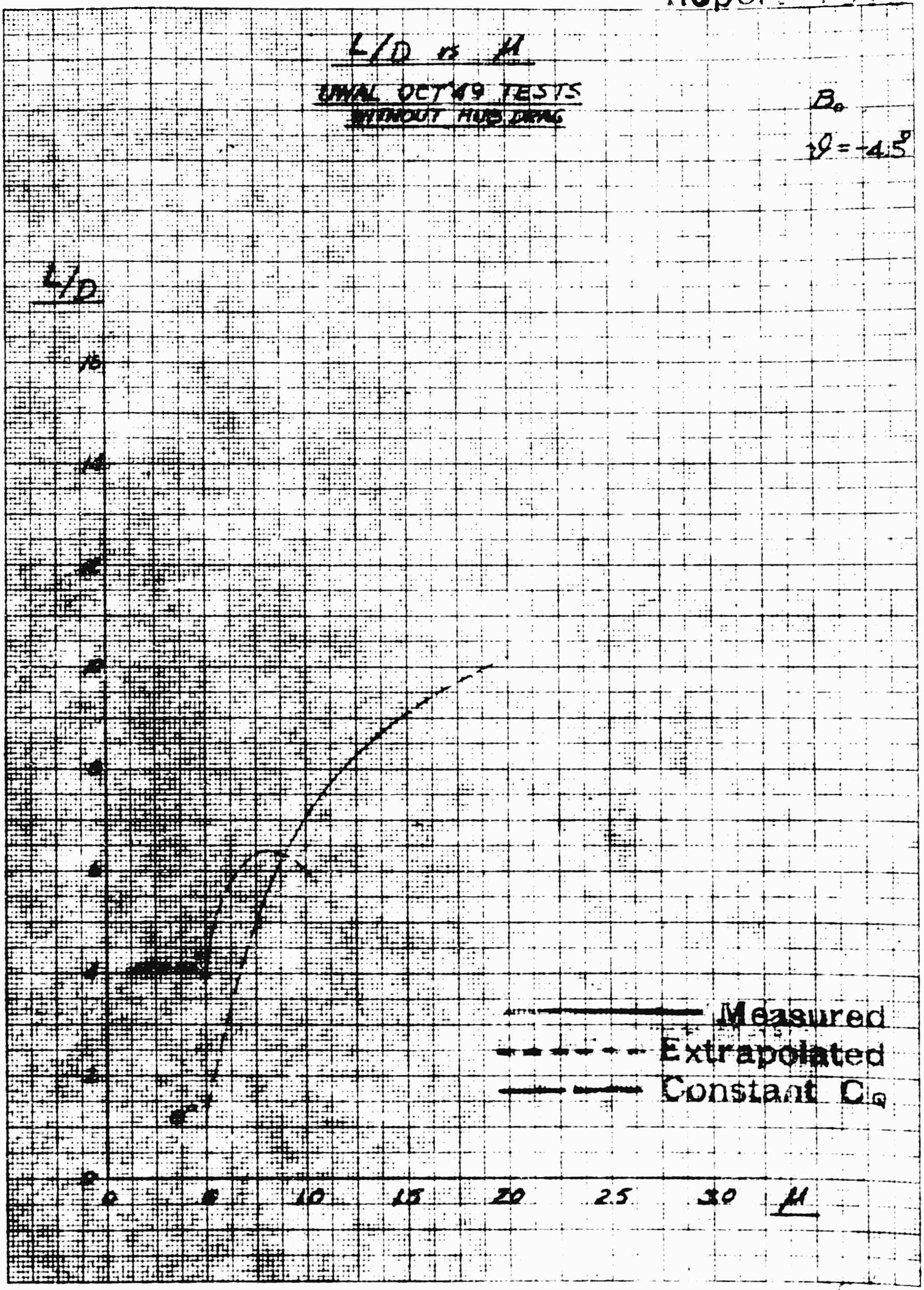


KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359.14 Millimeters, 5 mm lines accented, cm lines heavy

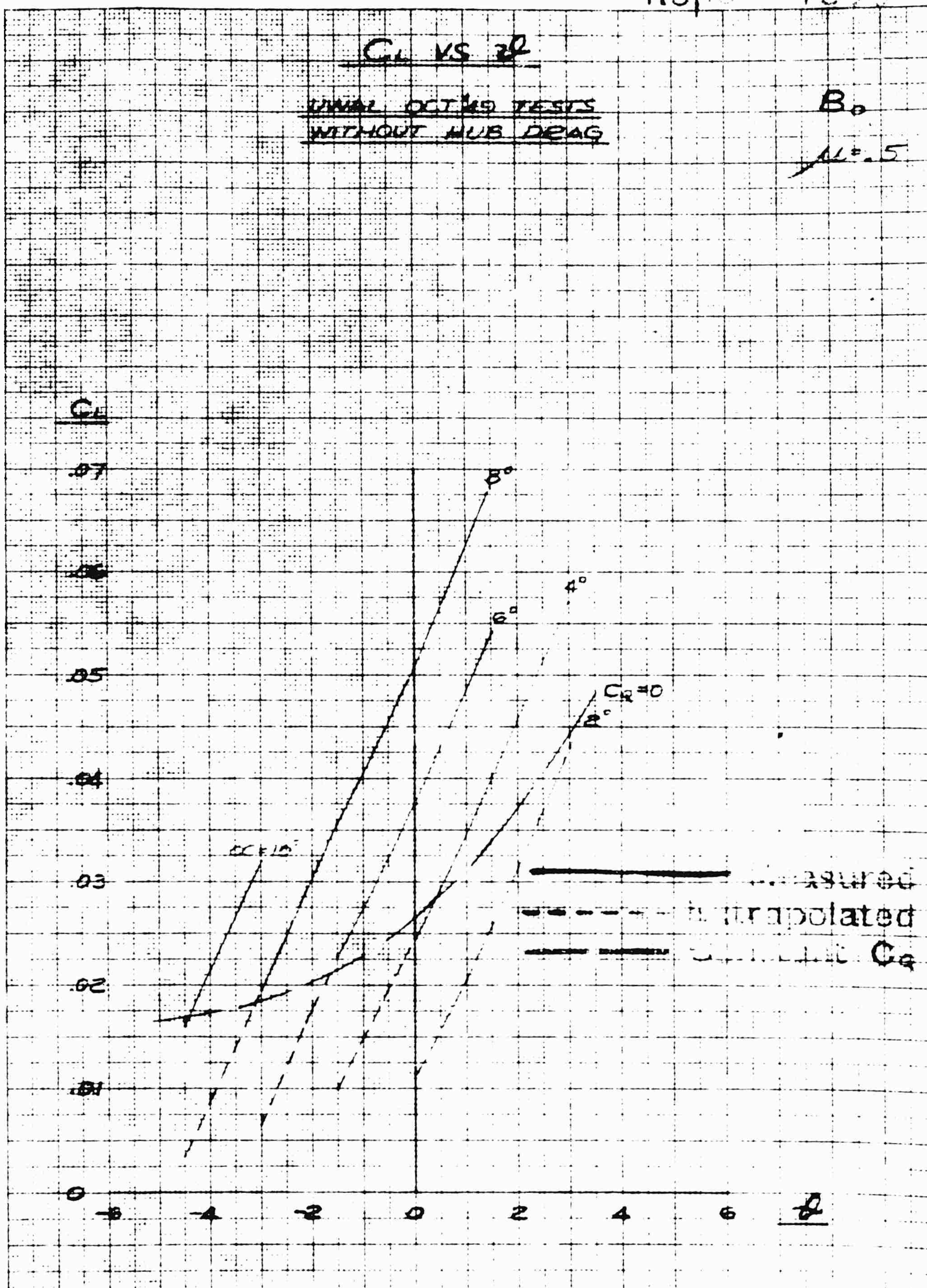
RPA
12-15-49



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

Log 197
Report 197

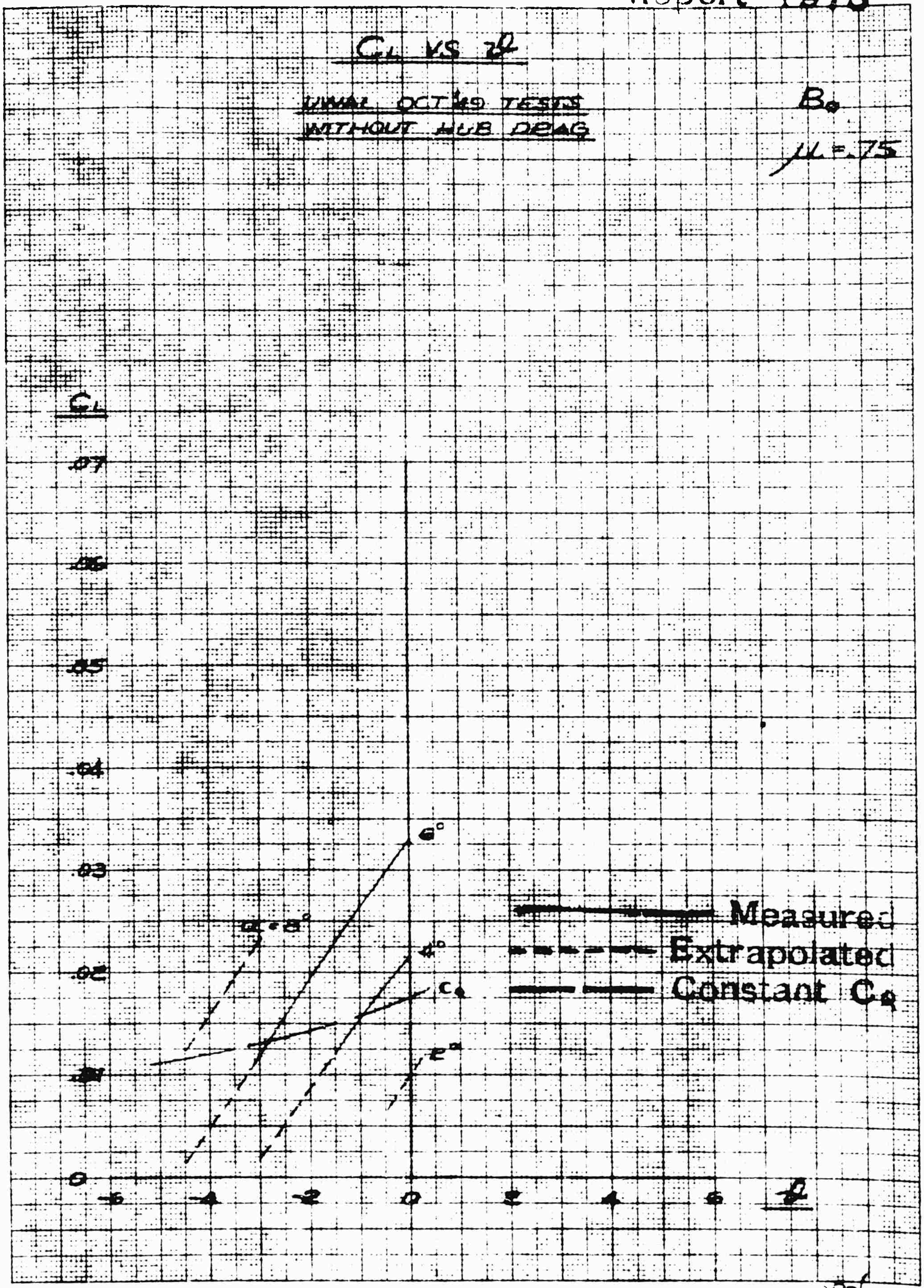


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

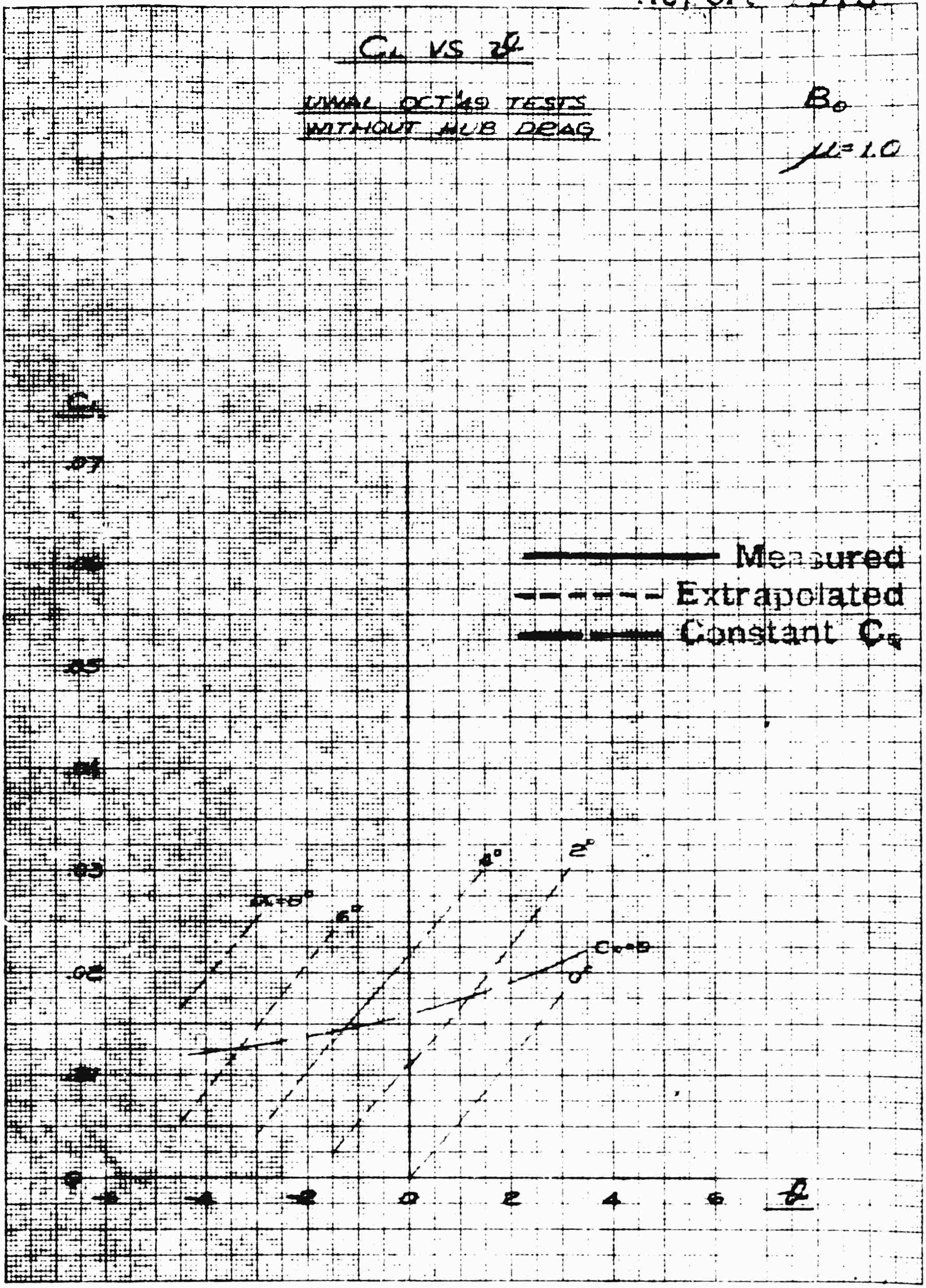
CONFIDENTIAL

F 198

Report 1975



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

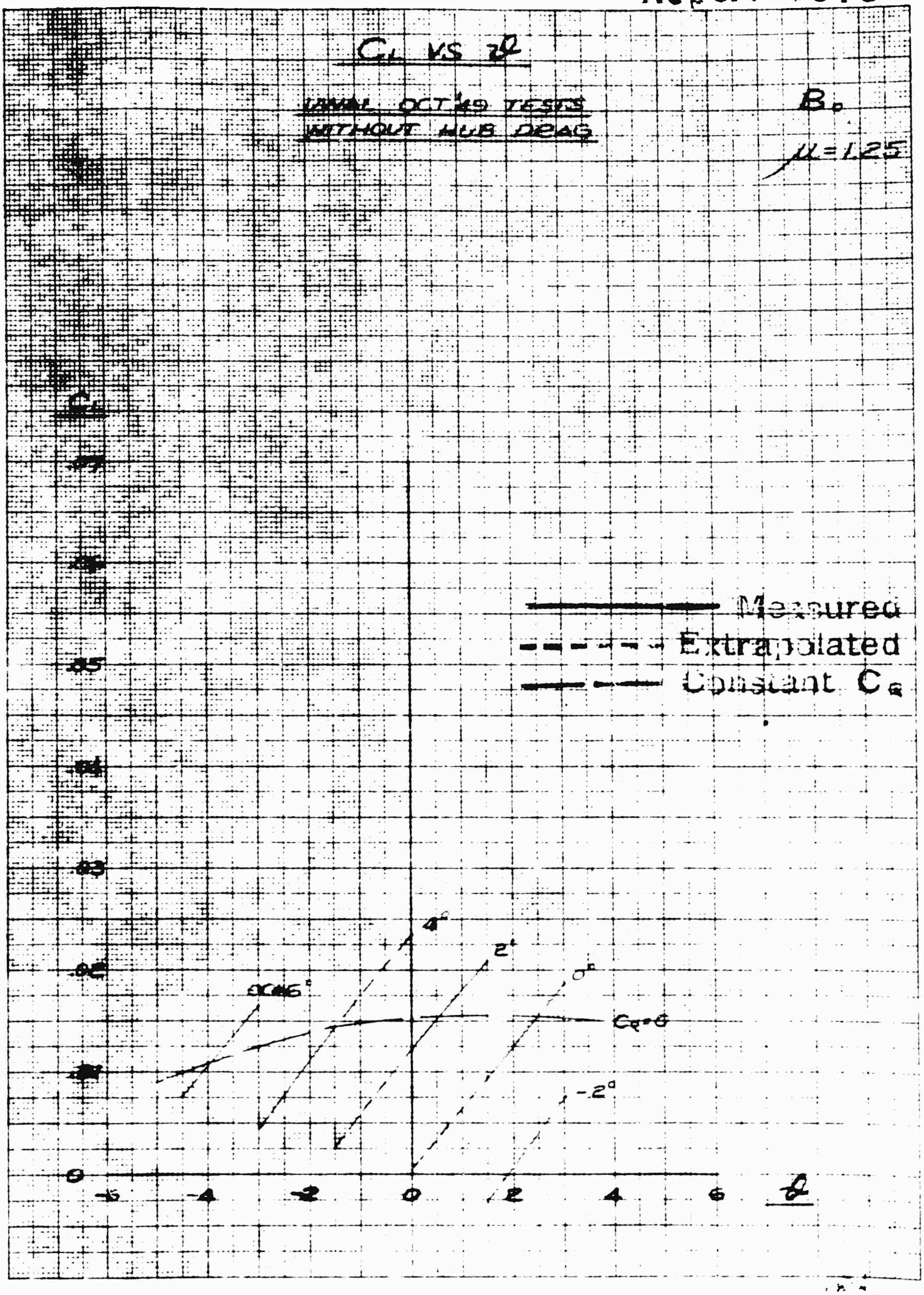


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

200

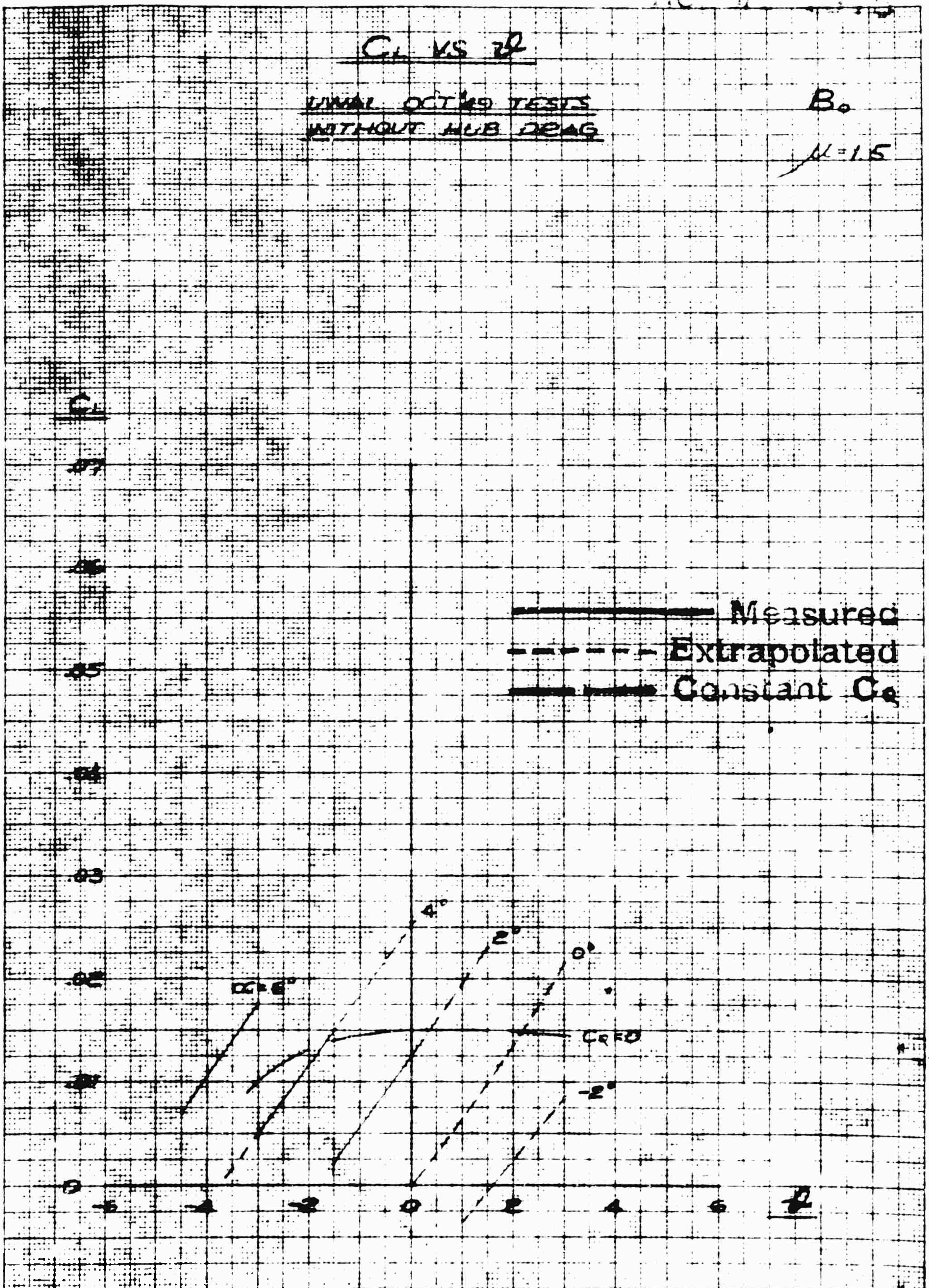
Report 1975



KEUFFEL & ESSER CO.

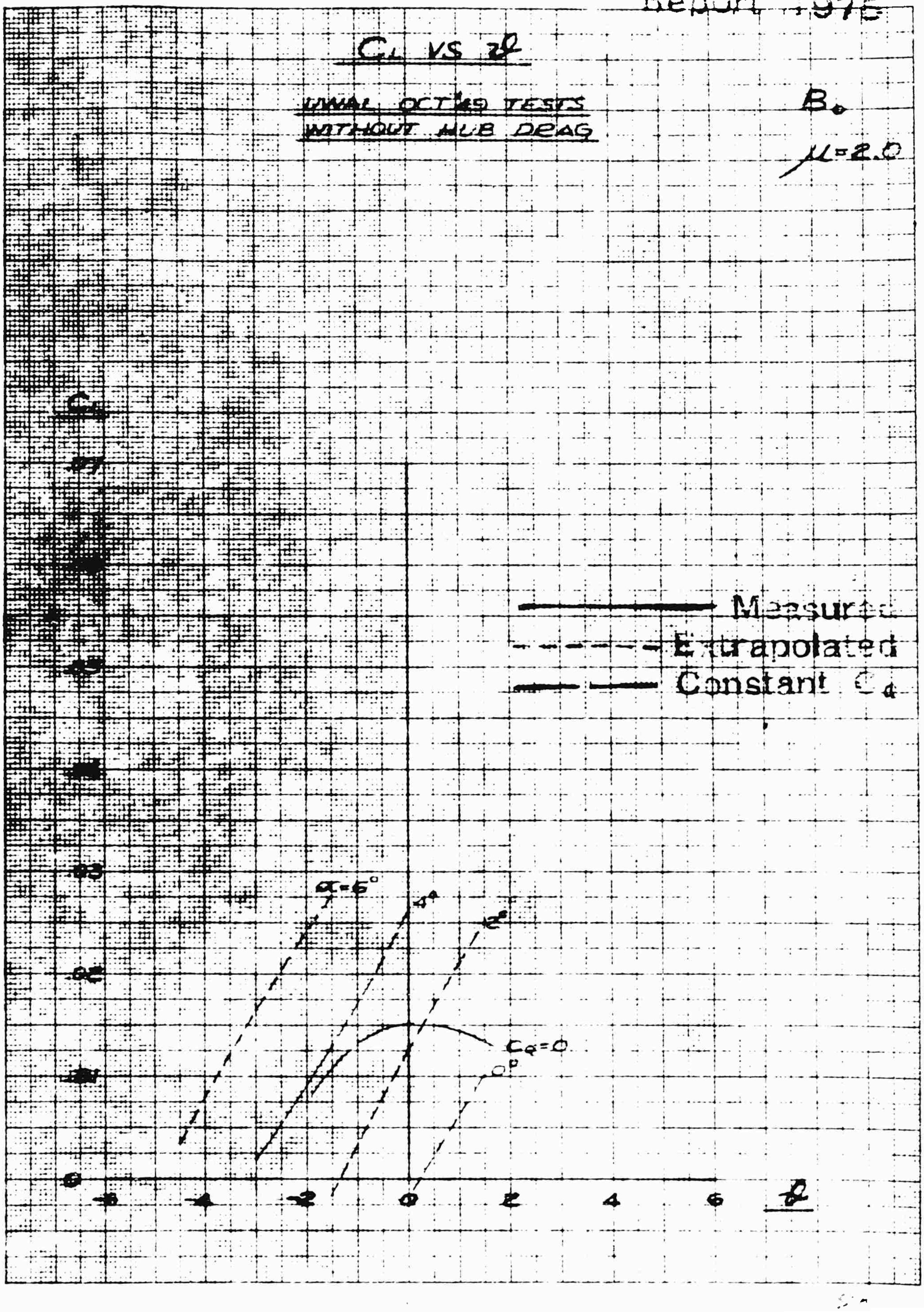
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

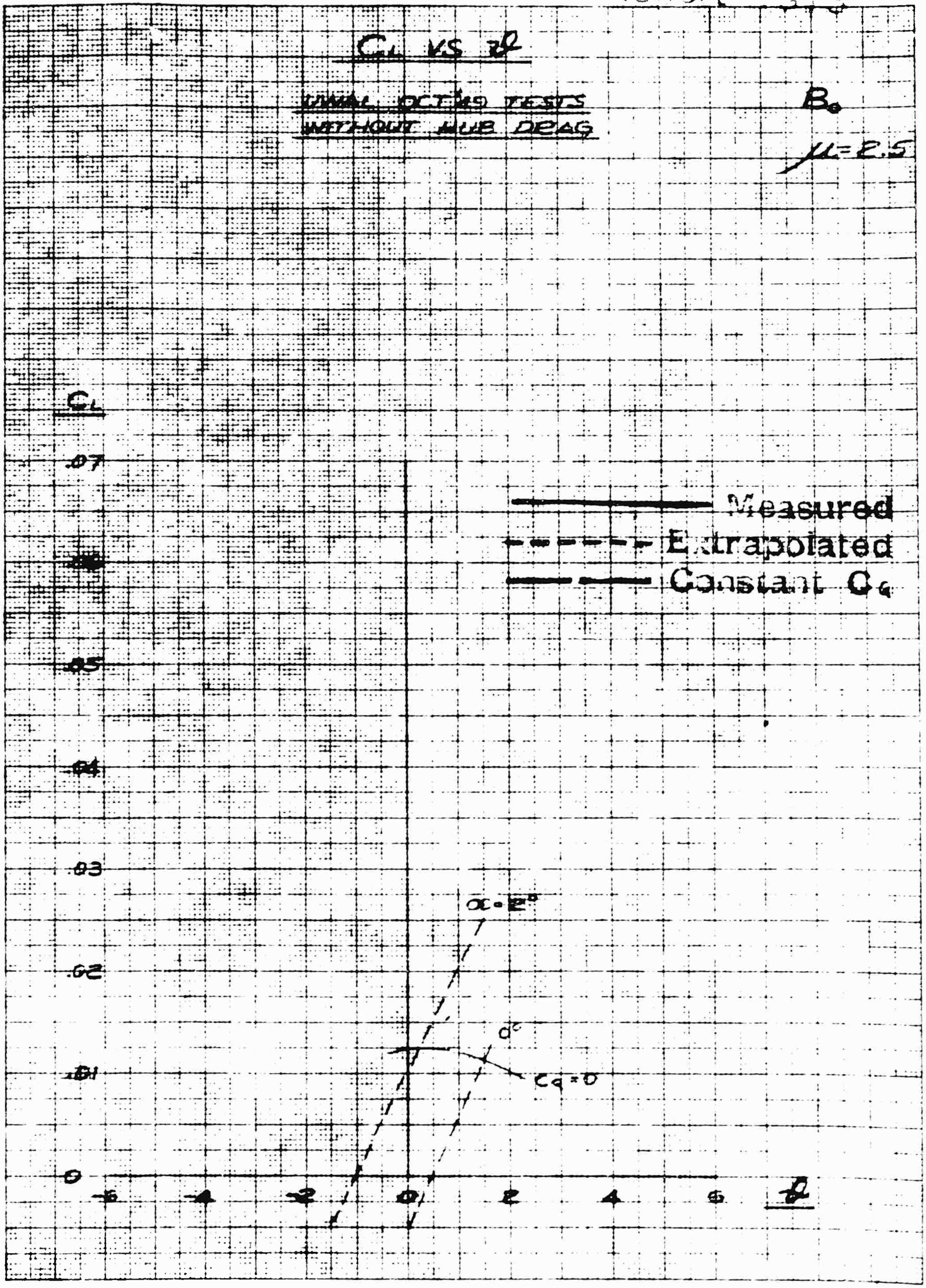


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

203

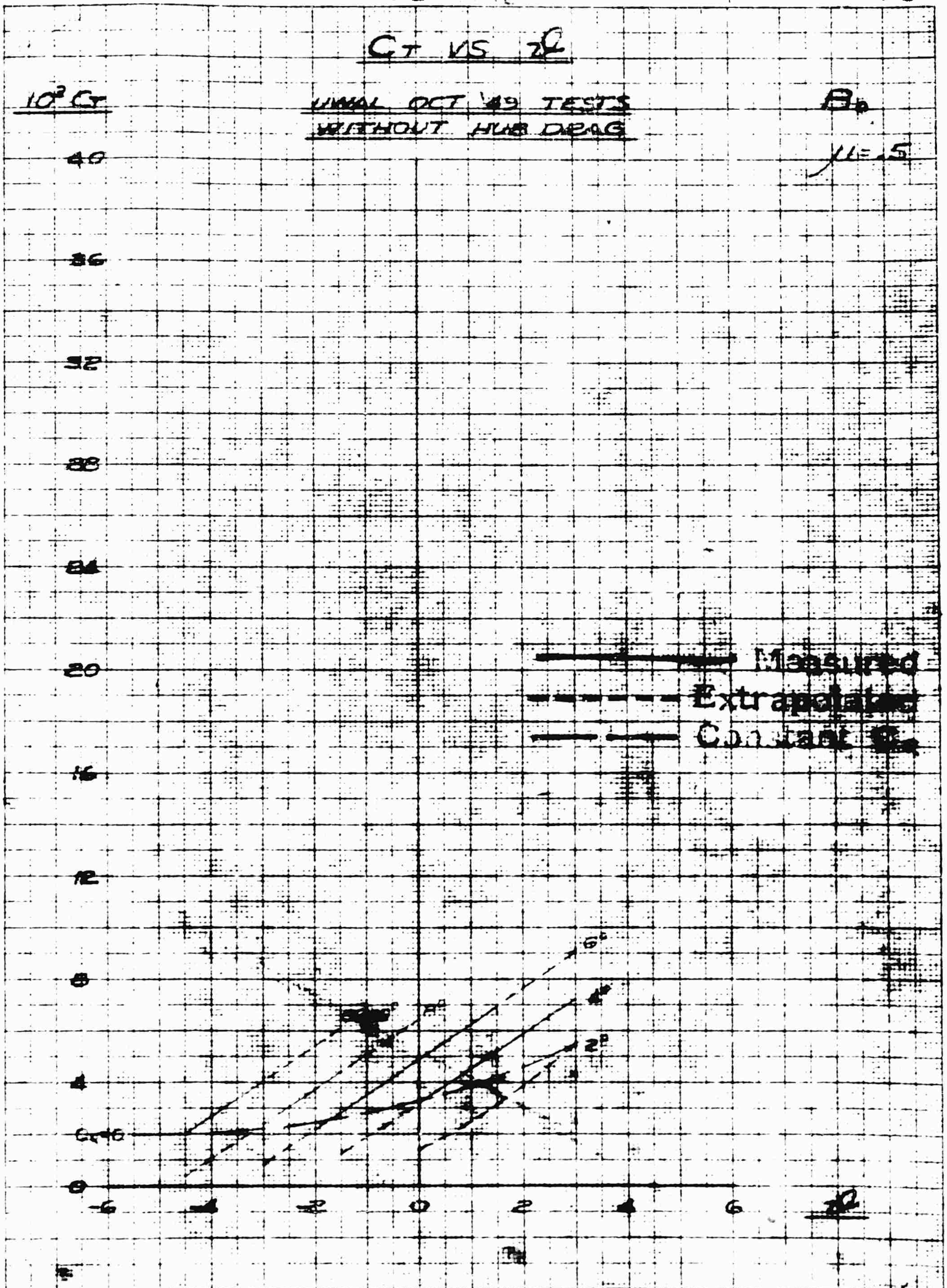
Report



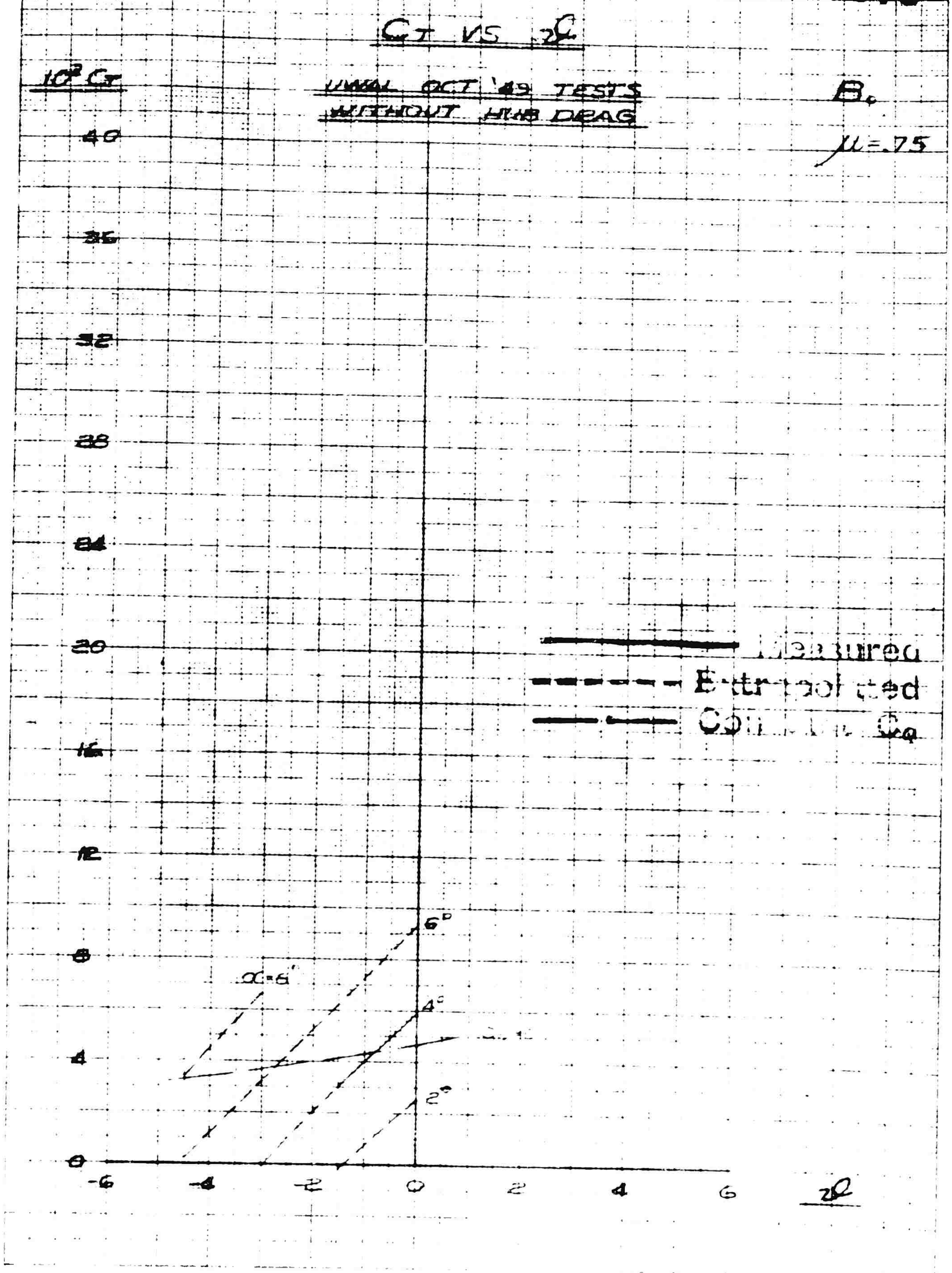
KEUFFEL & ESSER CO.

No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

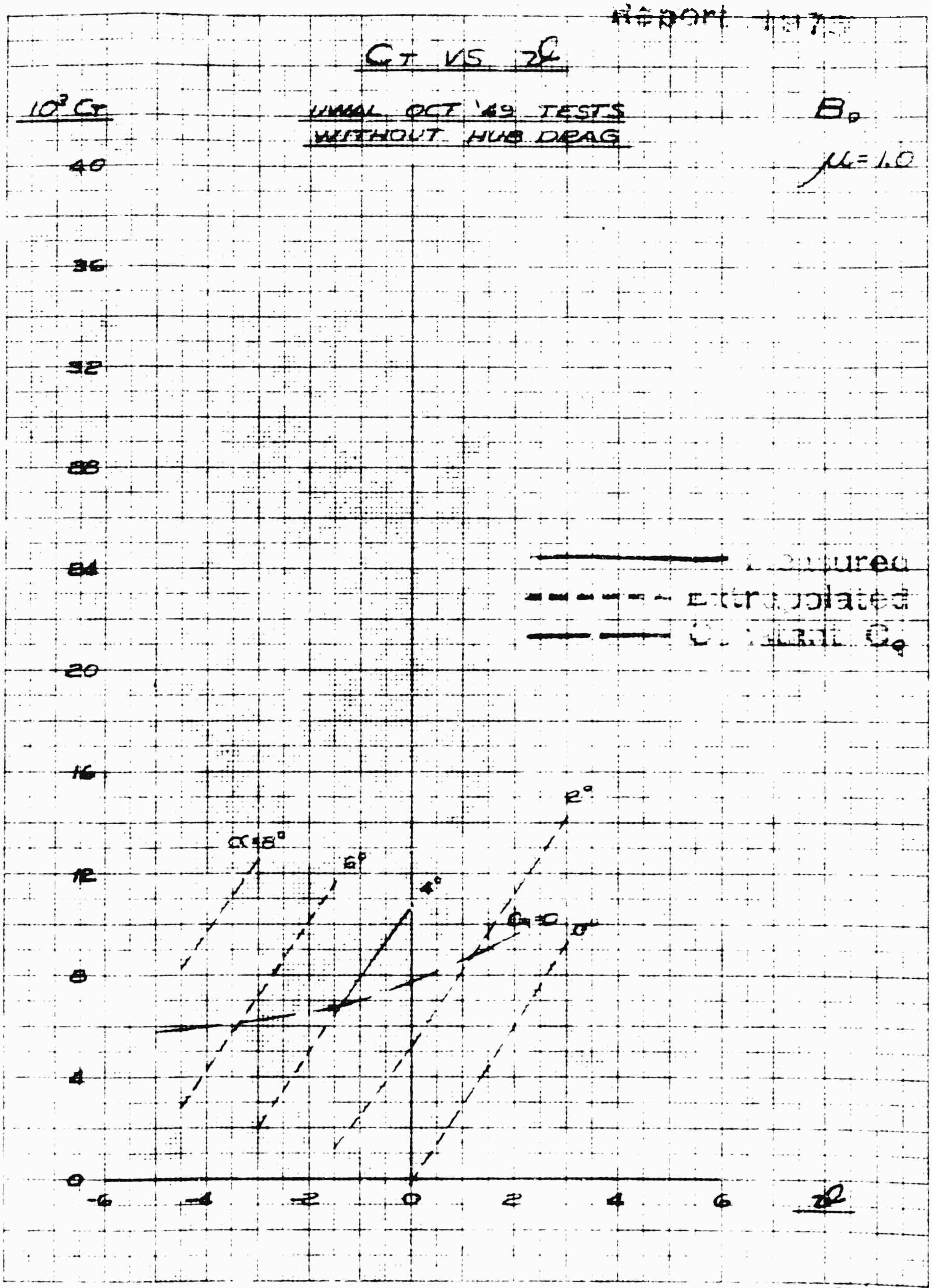
CONFIDENTIAL



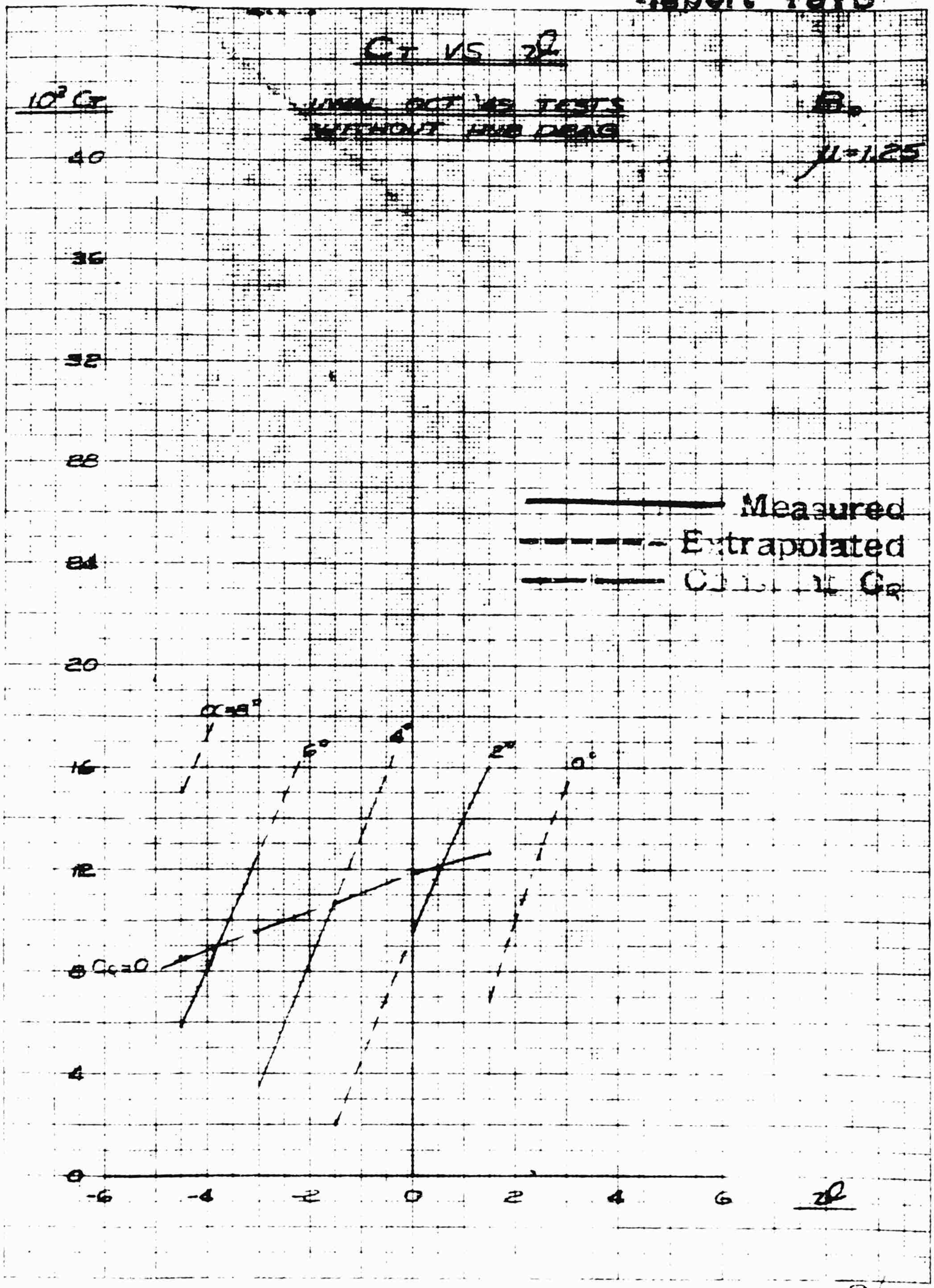
CONFIDENTIAL

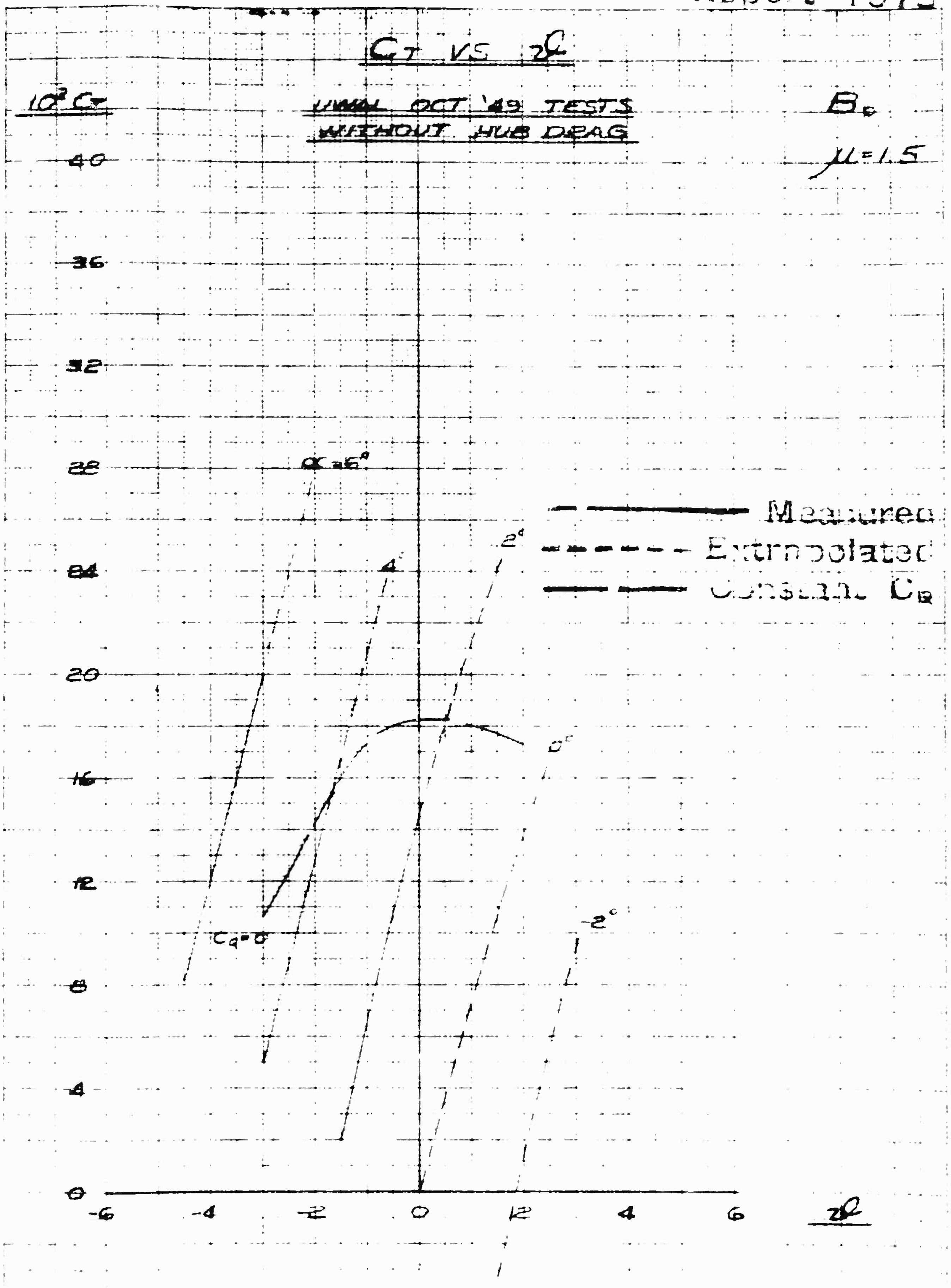

C_T VS $2C$
$10^2 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B.
$\mu = .75$
40
36
32
28
24
20
16
12
8
4
0
$\alpha = 6°$
6°
4°
2°
-6
-4
-2
0
2
4
6
$2C$

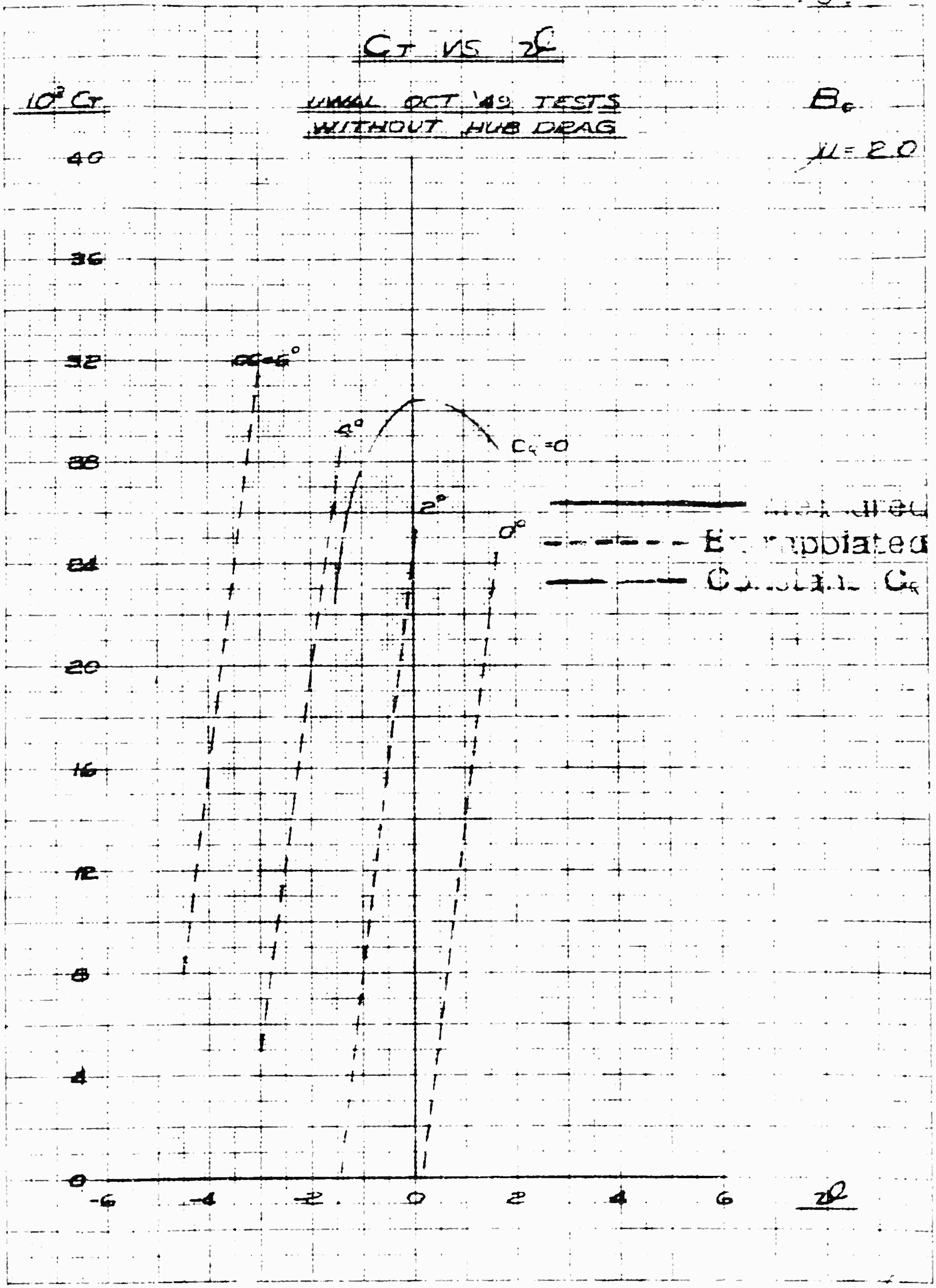
Report

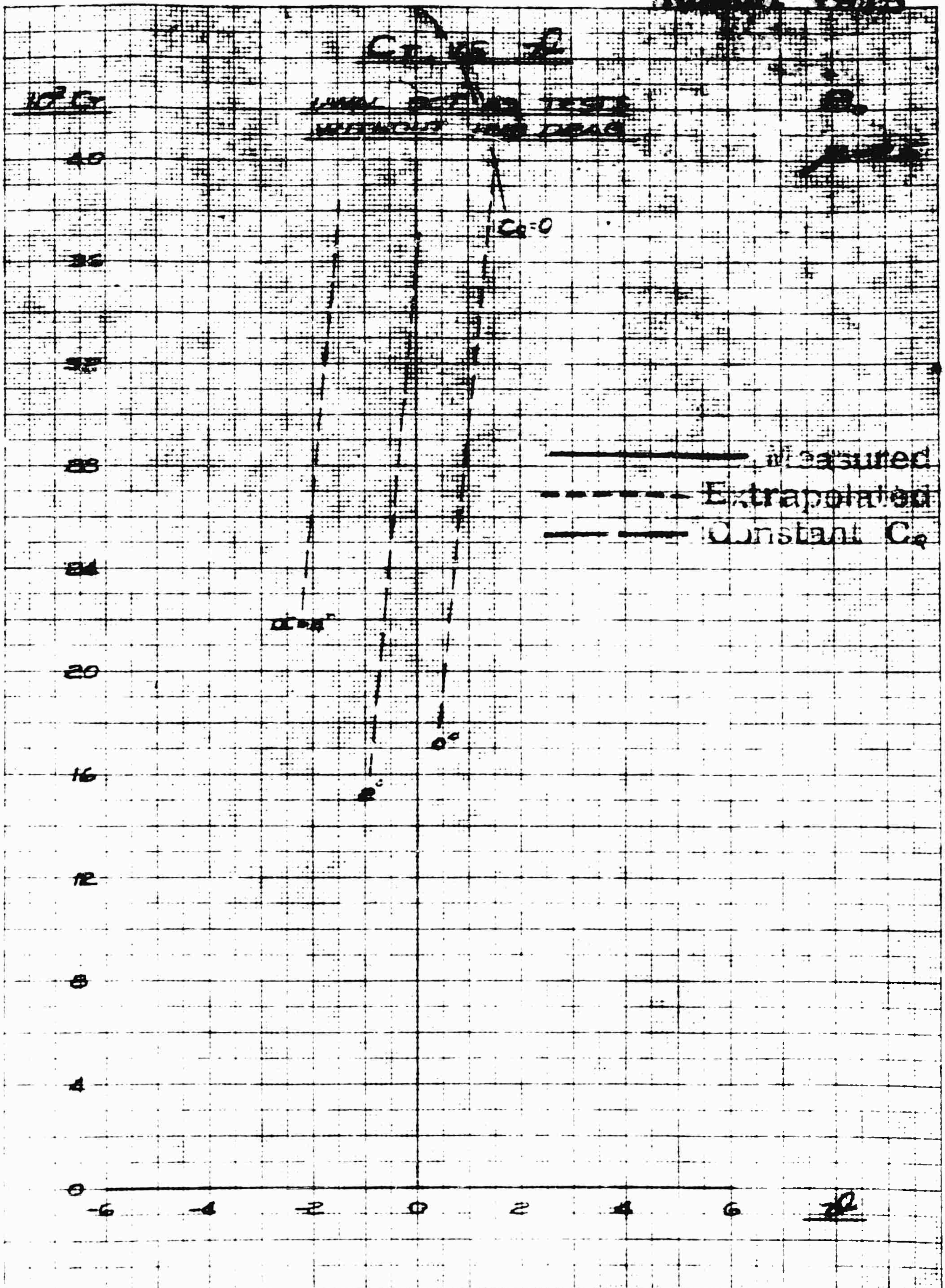


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

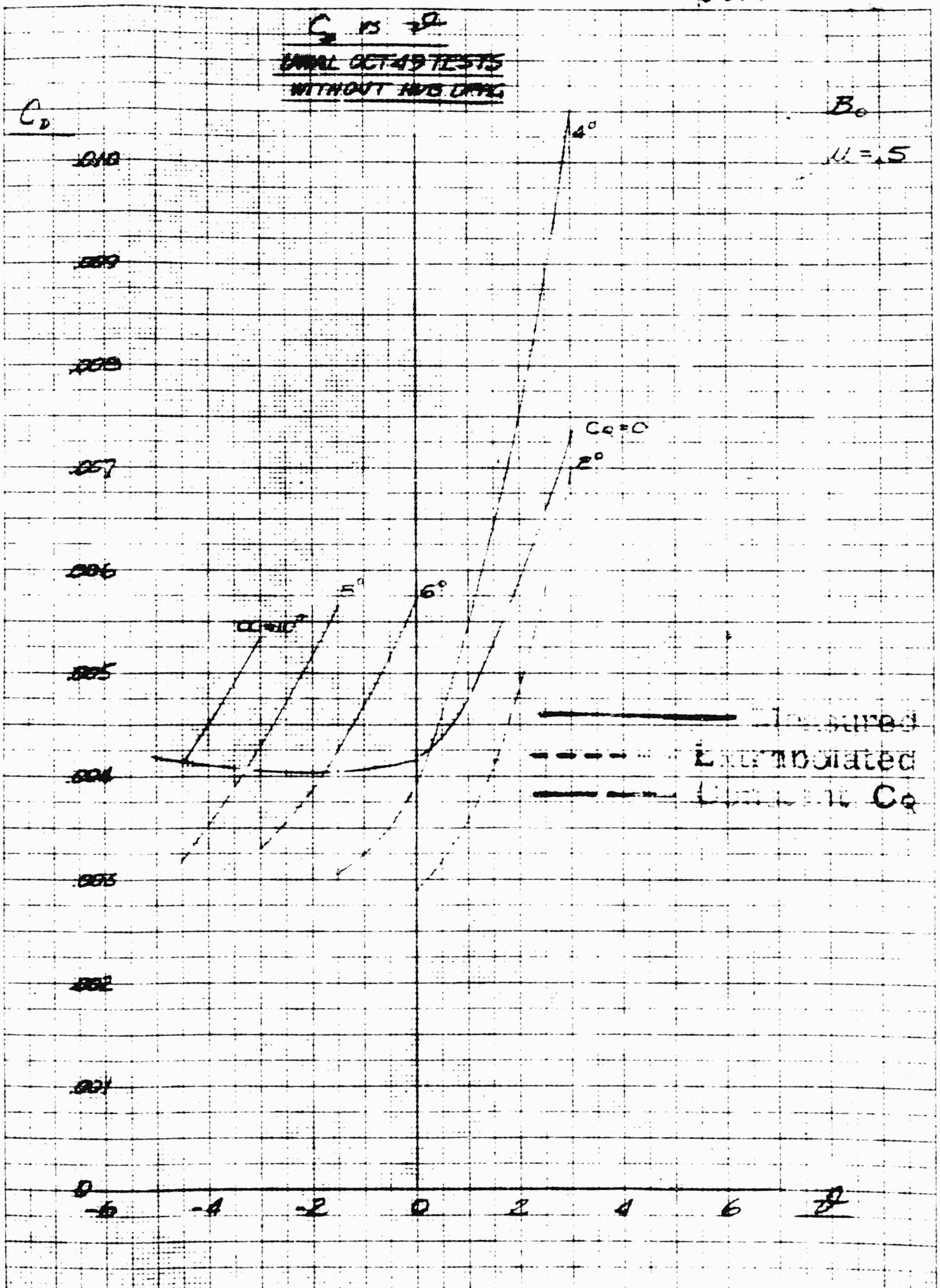

C_T VS θ
WIND OCT VS TESTS
WITHOUT HUB DRAG
B
μ=1.25
$10^3 C_T$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
θ
Measured
Extrapolated
C_Q
α=8°
6°
4°
2°
0°
C_Q=0


C_T VS θ
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
μ=1.5
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
θ
α=6°
4°
2°
0°
-2°
C_Q=0
Measured
Extrapolated
Constant C_R

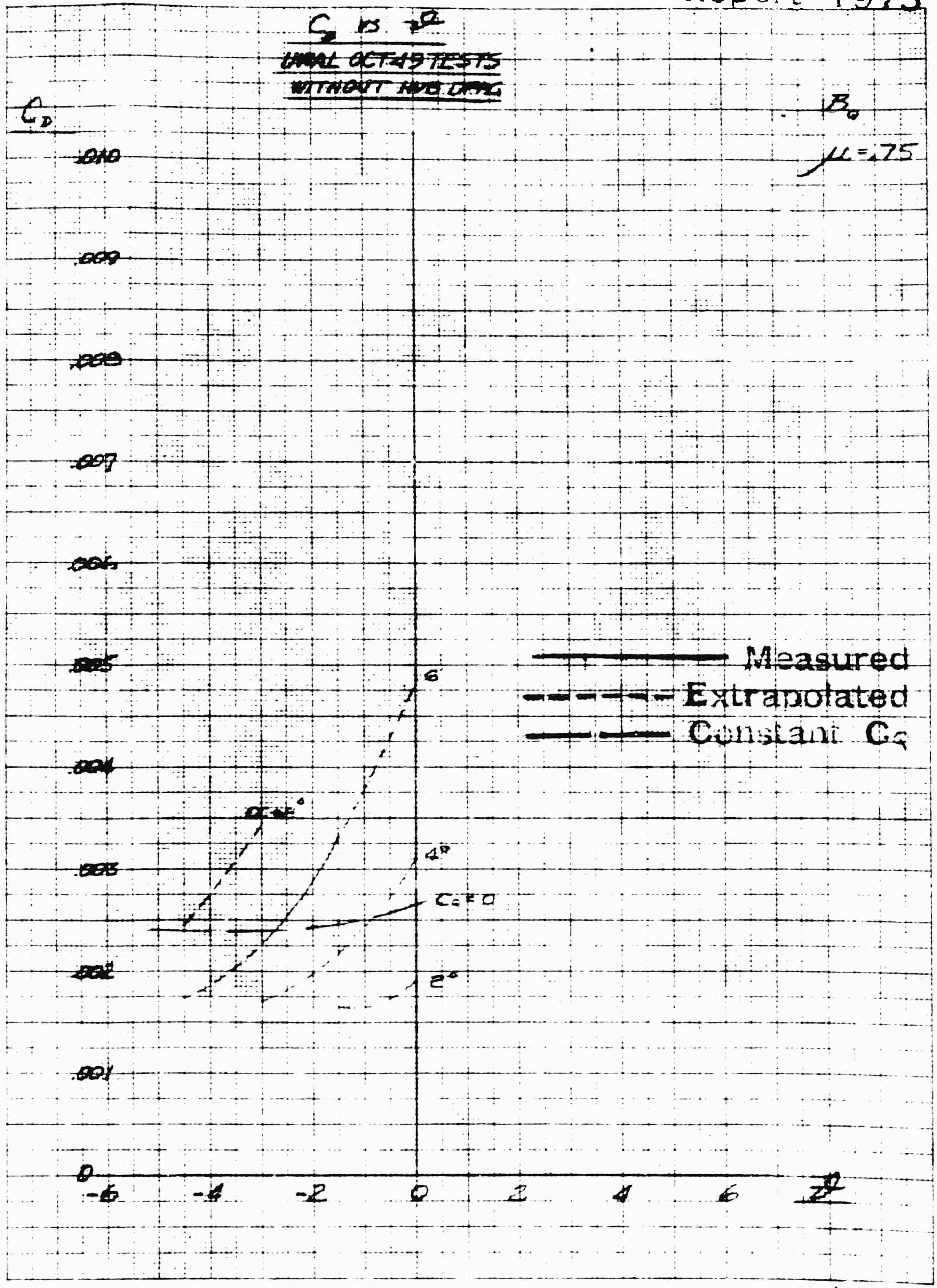

CT VS θ
10^3 CT
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B6
μ = 2.0
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
θ
6°
4°
2°
0°
CQ = 0
Extrapolated
Constant CQ



KEUFFEL & ESSER CO

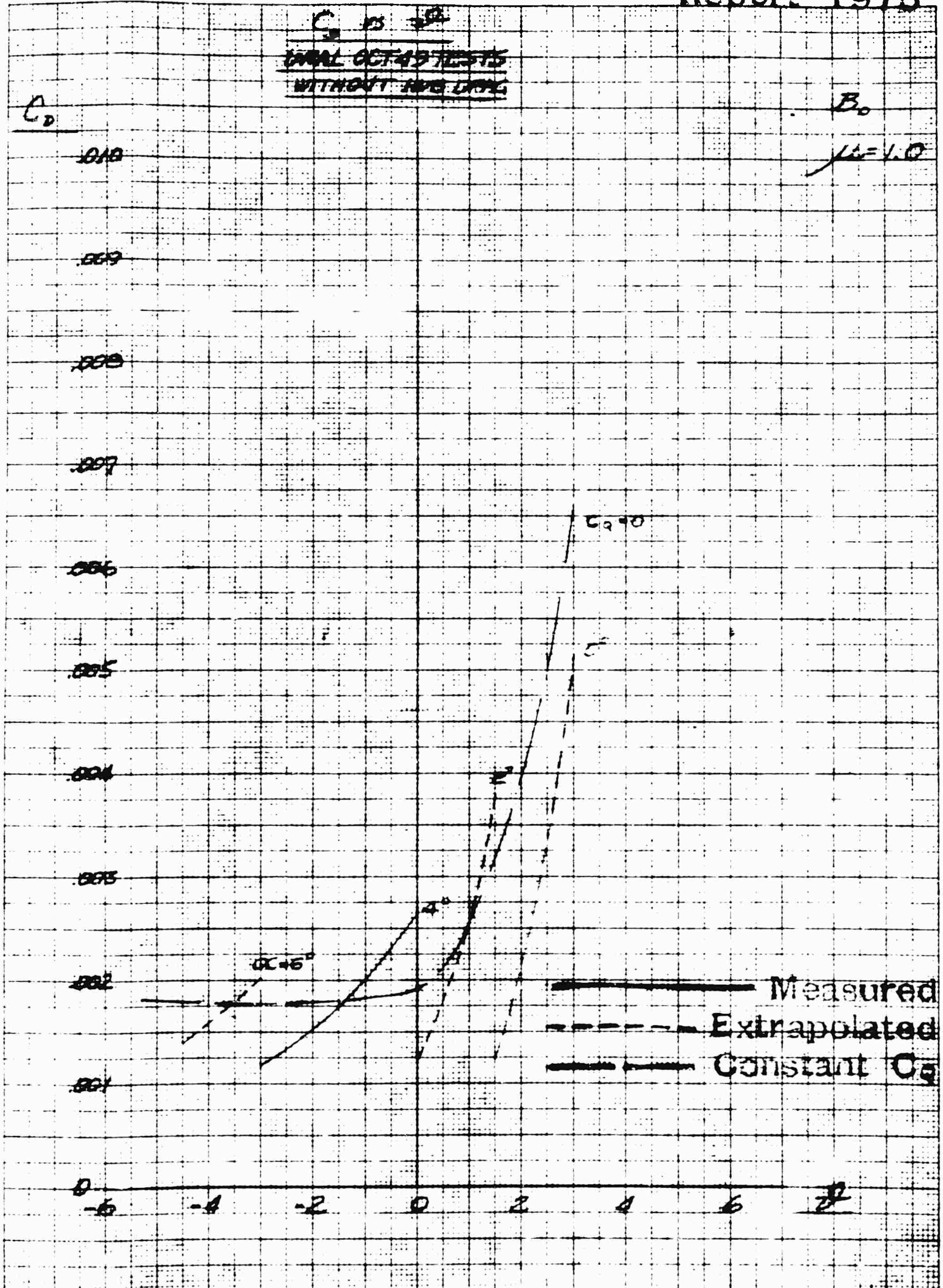


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



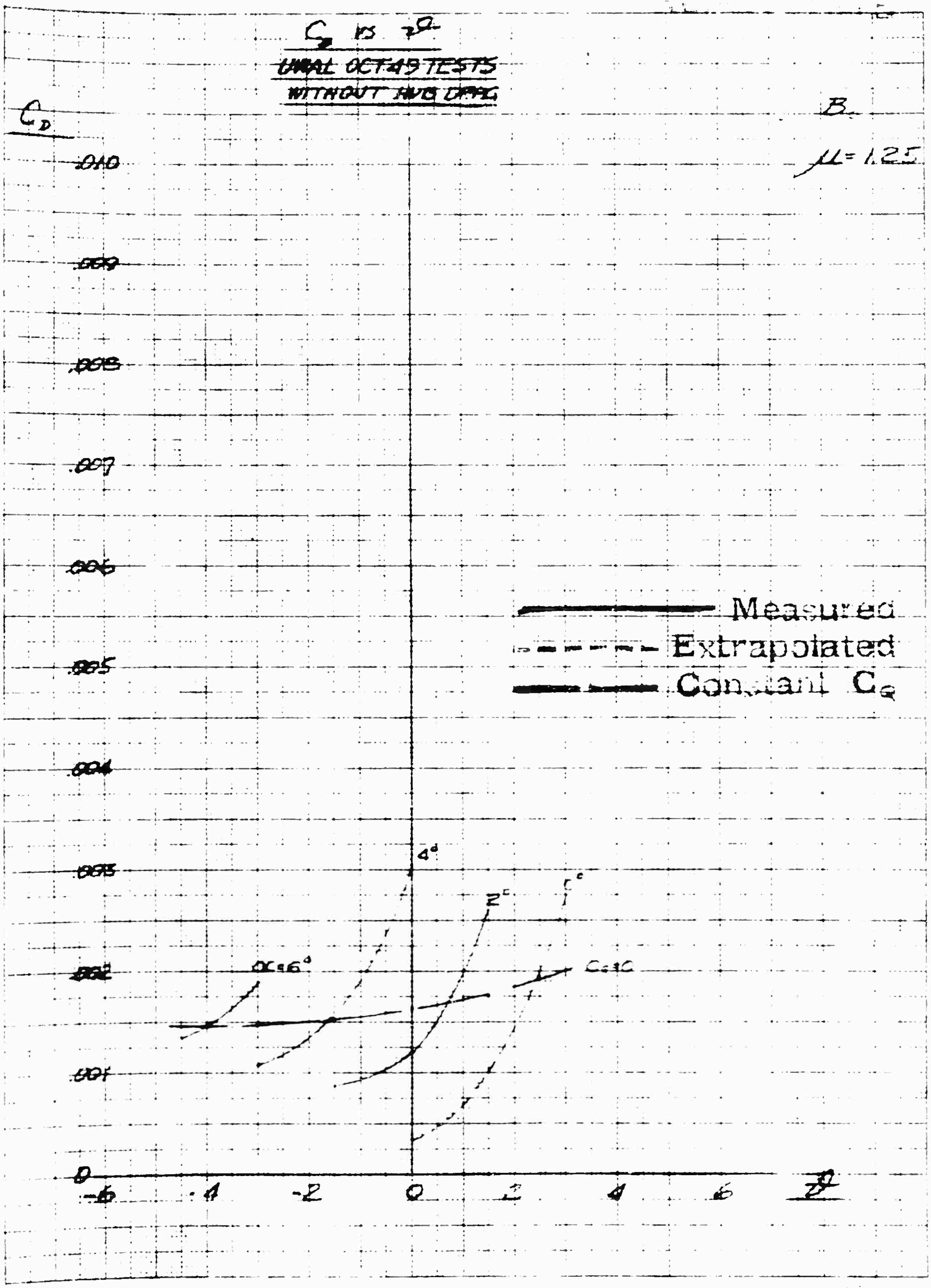
KEUFFEL & ESSER CO.

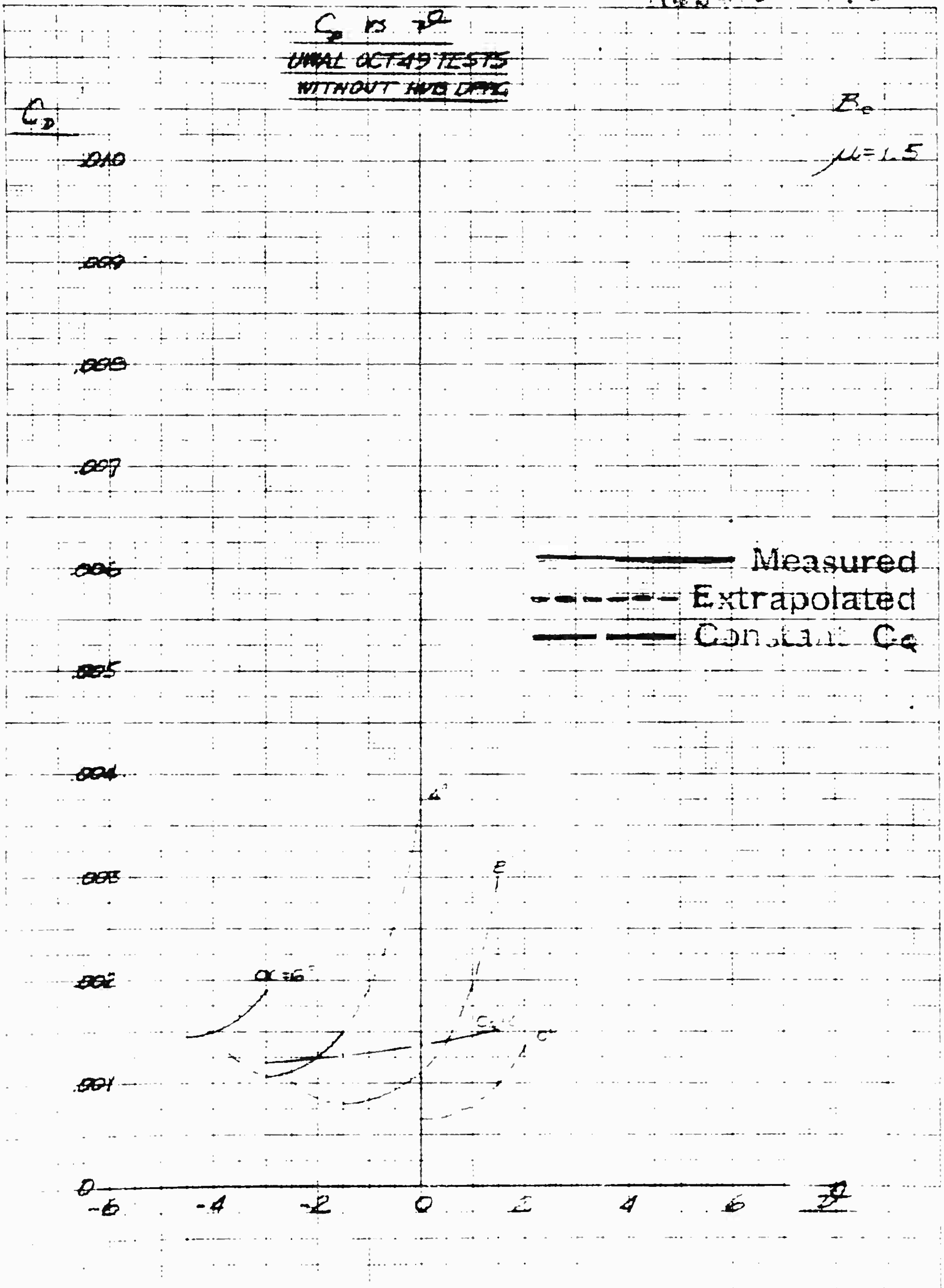
CONFIDENTIAL



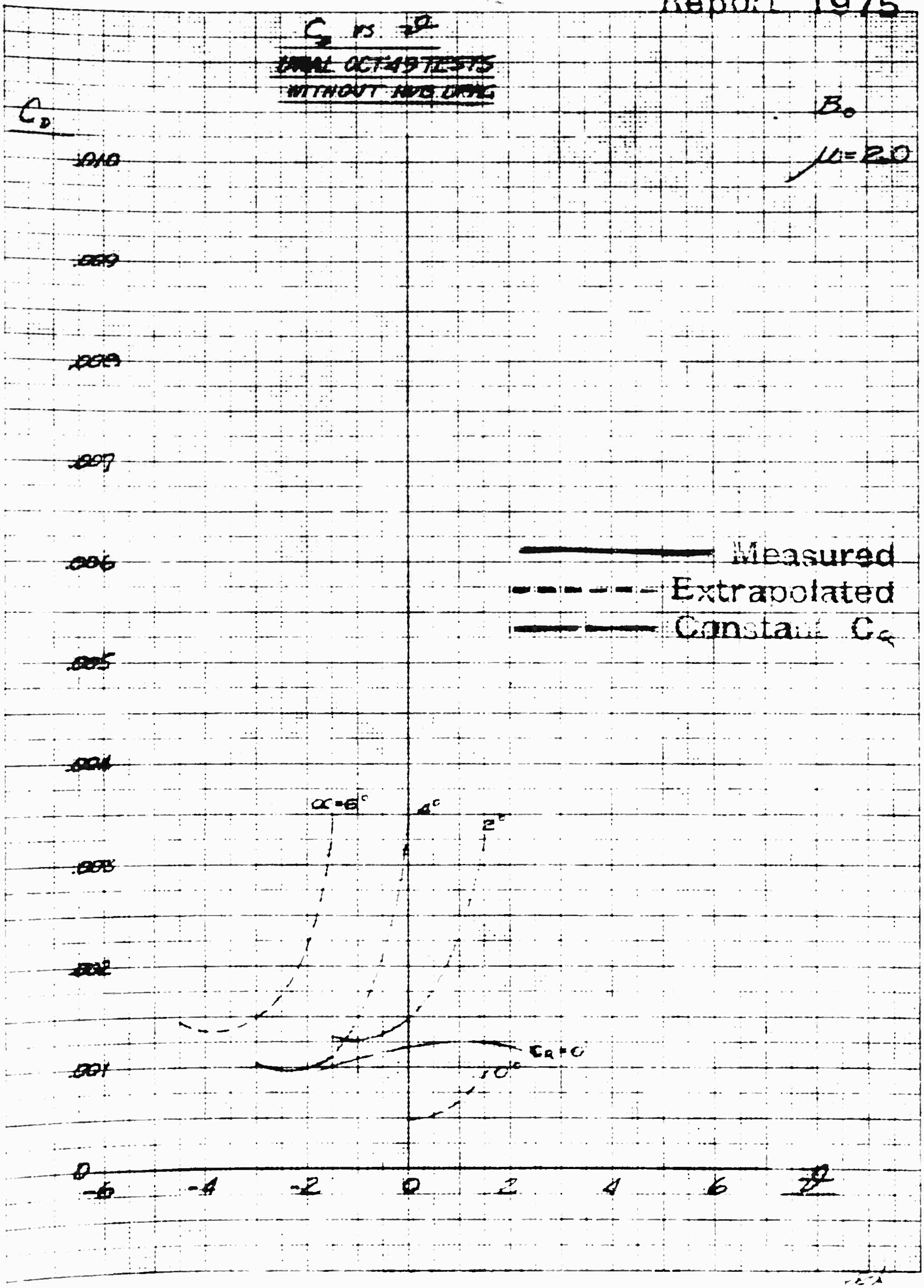
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

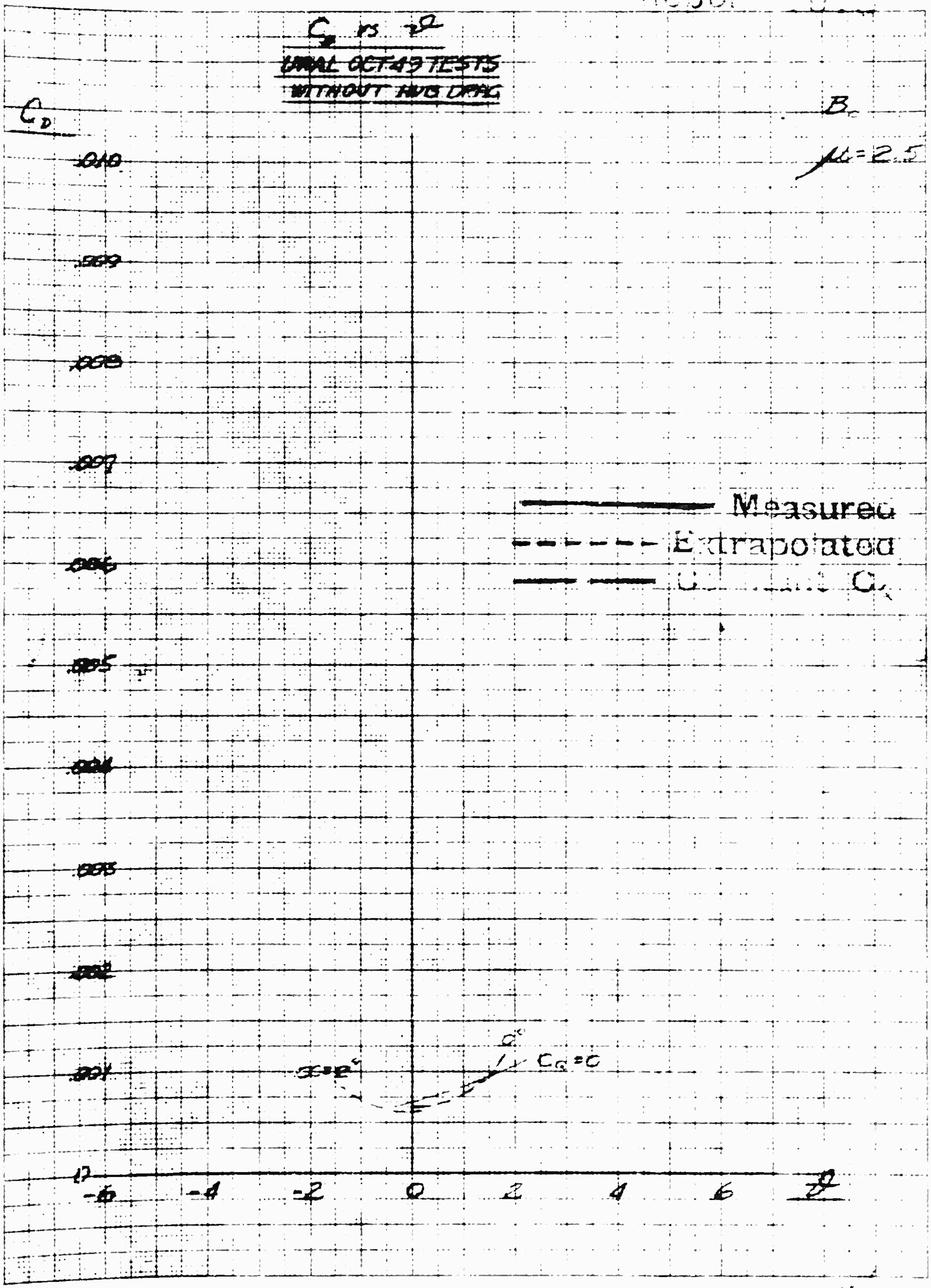
38.H
12-12-49


C_D vs θ
UMAL OCT 49 TESTS
WITHOUT HUB DRAG
B.
$\mu = 1.25$
C_D
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
θ
$4°$
$2°$
$\alpha = 6°$
$C_Q = C$
Measured
Extrapolated
Constant C_Q

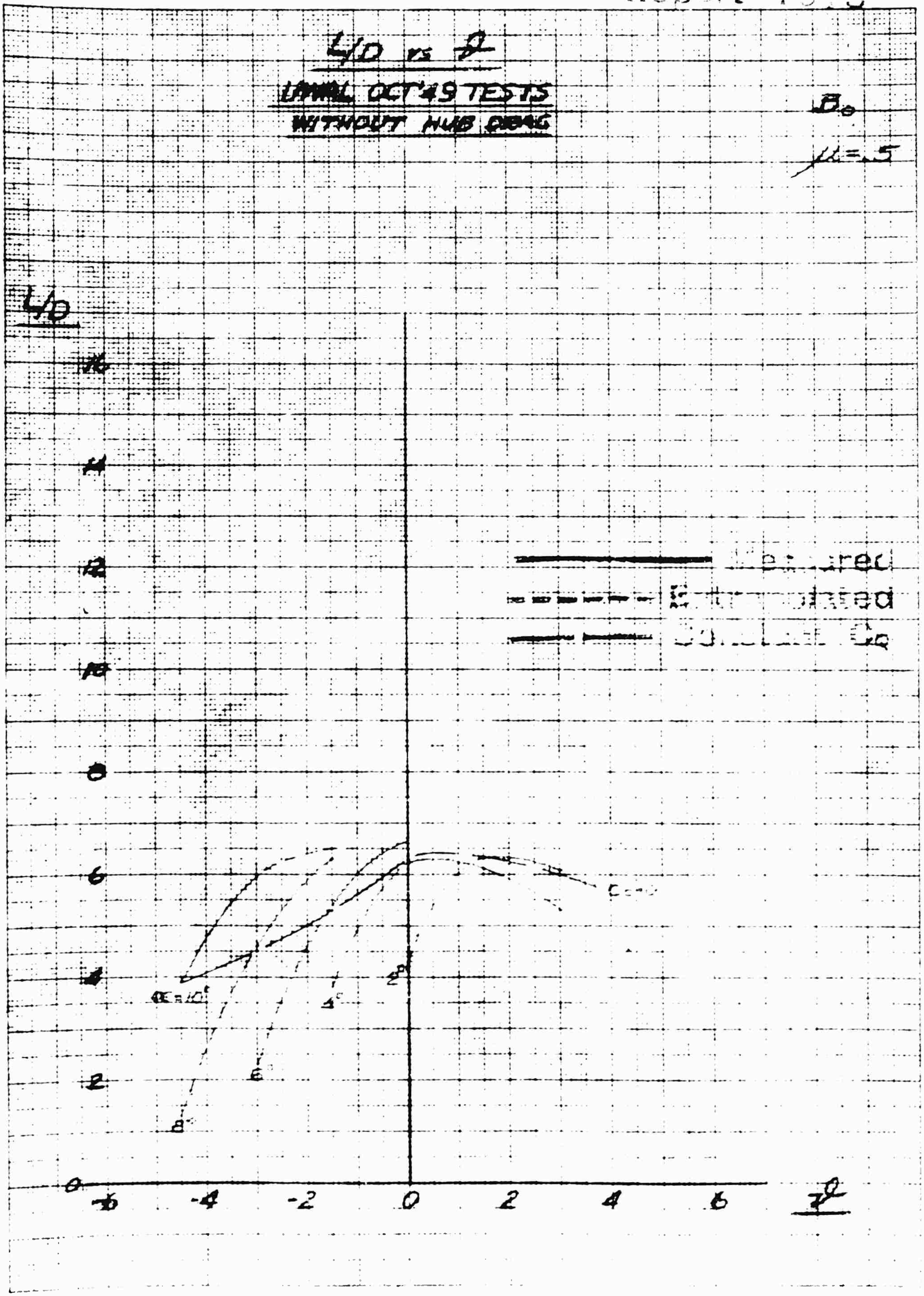

C_D vs θ
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
C_D
B_e
$\mu = 1.5$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
θ
$\alpha = 6°$
Measured
Extrapolated
Constant C_Q

CONFIDENTIAL

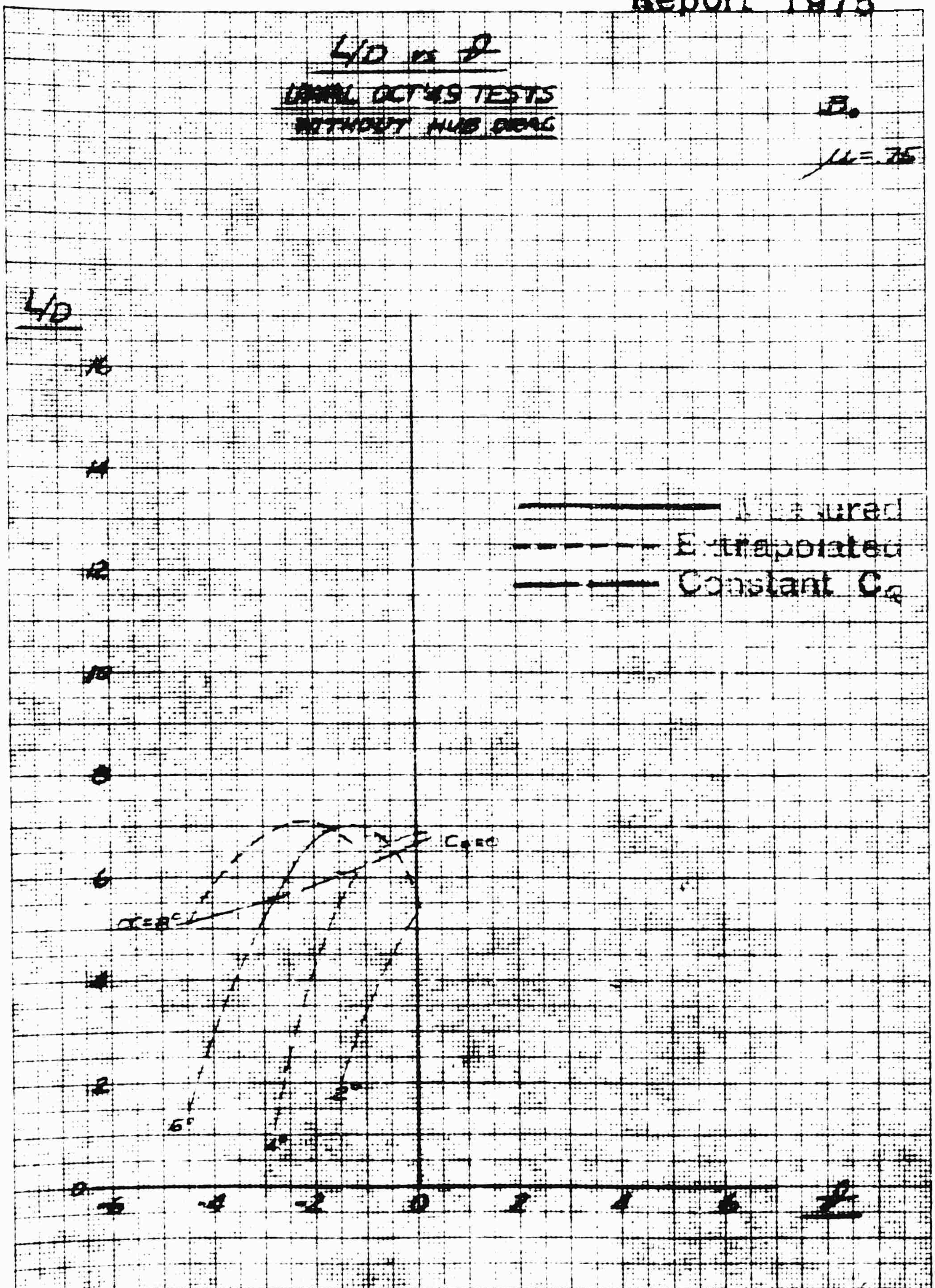


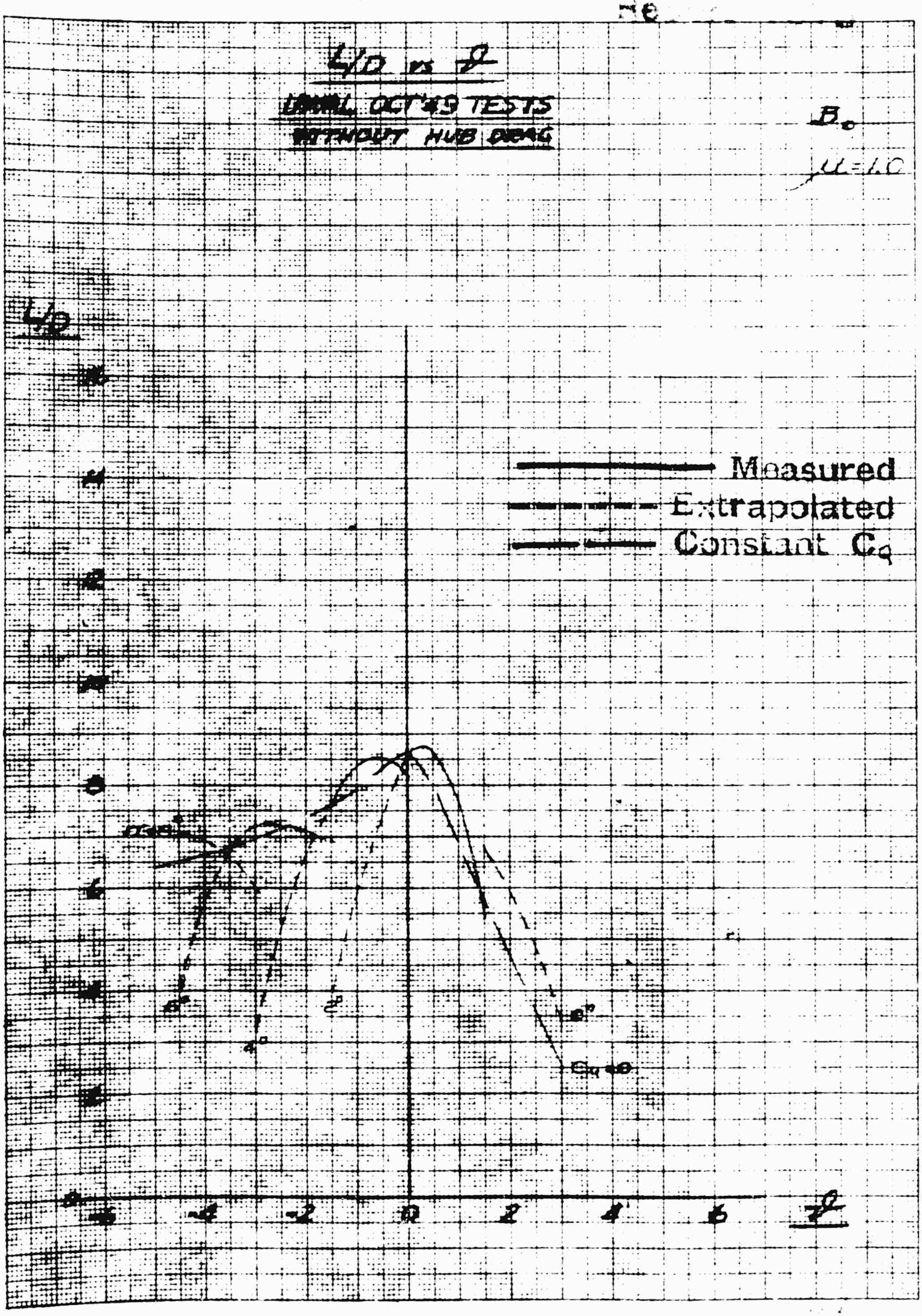

WITHOUT HUB DRAG
C_D
B_c
$\mu = 2.5$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
Measured
Extrapolated
$C_Q = 0$

Report 1975

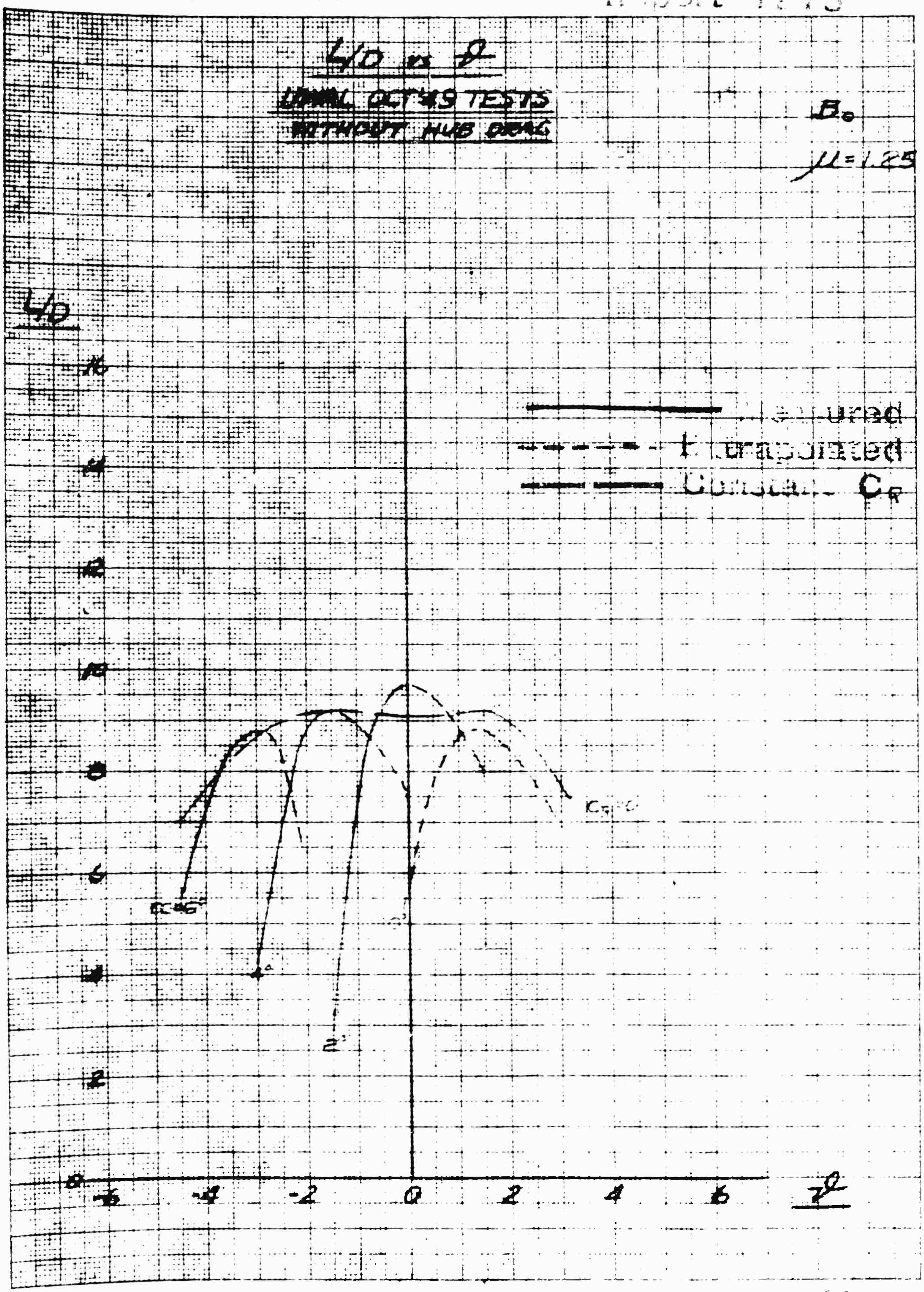


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy


L/D vs β
UWAL OCT '45 TESTS
WITHOUT HUB DRAG
B.
μ = .75
L/D
16
14
12
10
8
6
4
2
0
-6
-4
-2
0
2
4
6
β
Measured
Extrapolated
Constant C_Q
C_Q=0
α=8°
6°
4°
2°

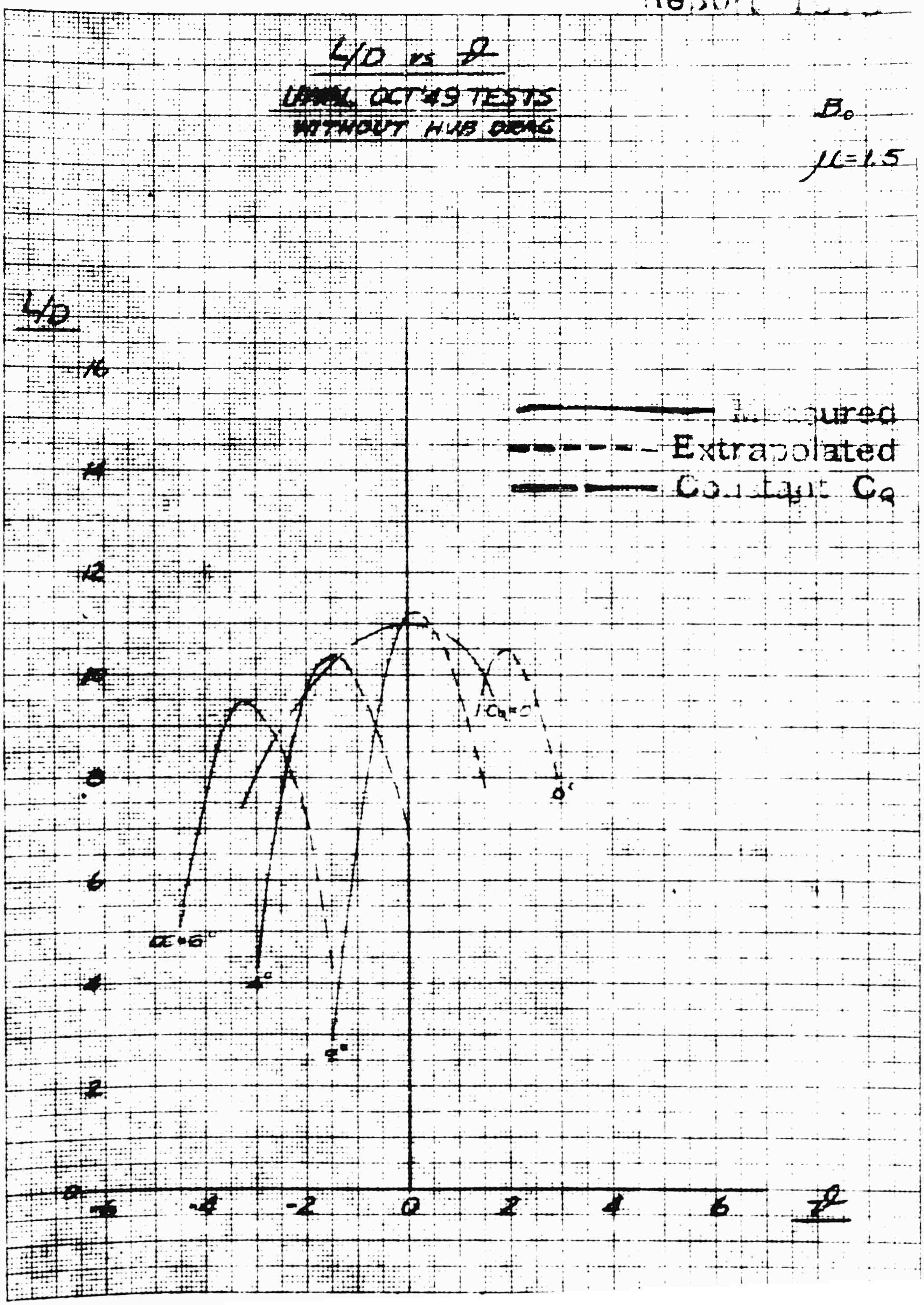


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

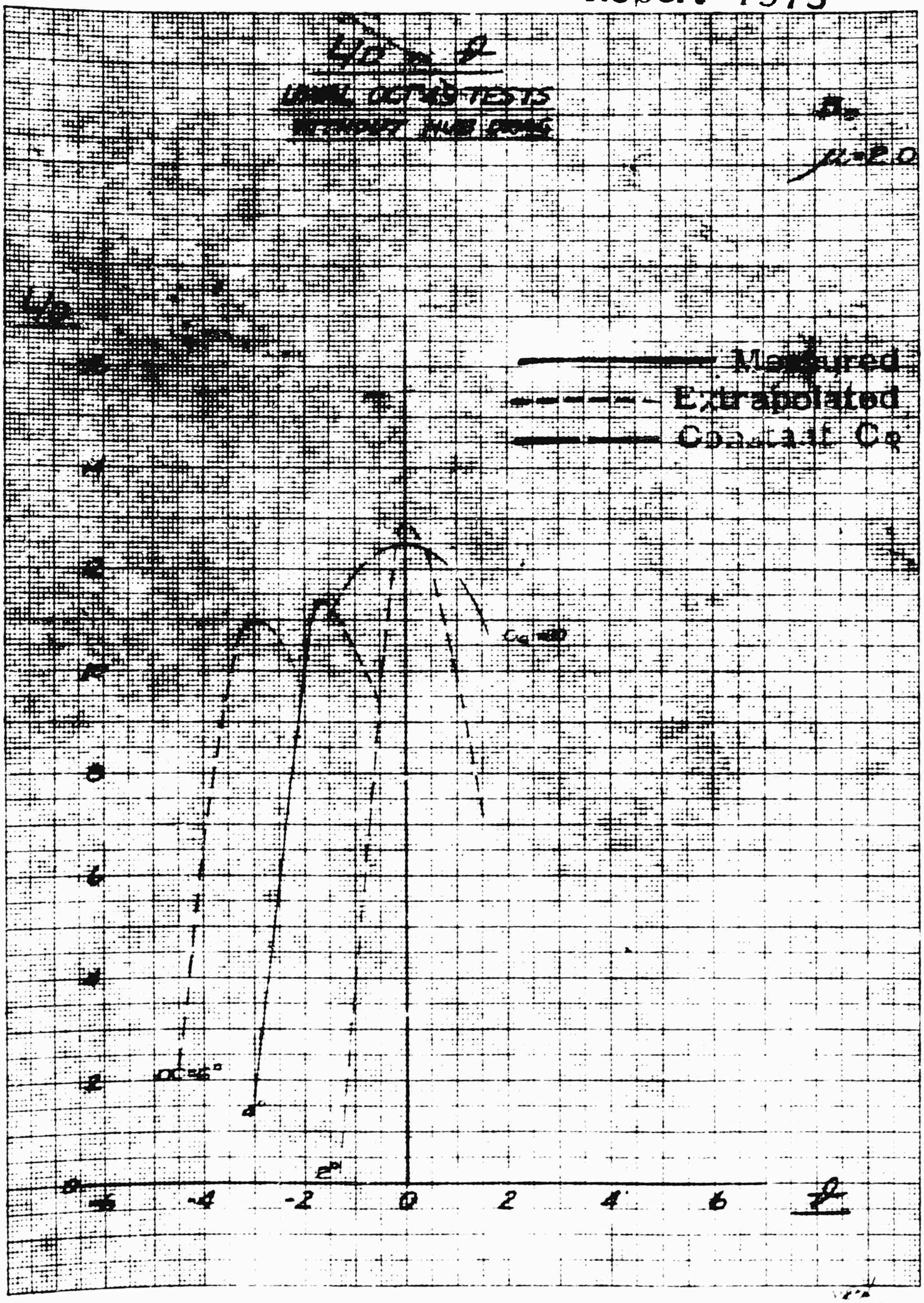


KEUFFEL & ESSER CO.
No 359.14 Millimeters, 5 mm lines accented, cm lines heavy

Report 222

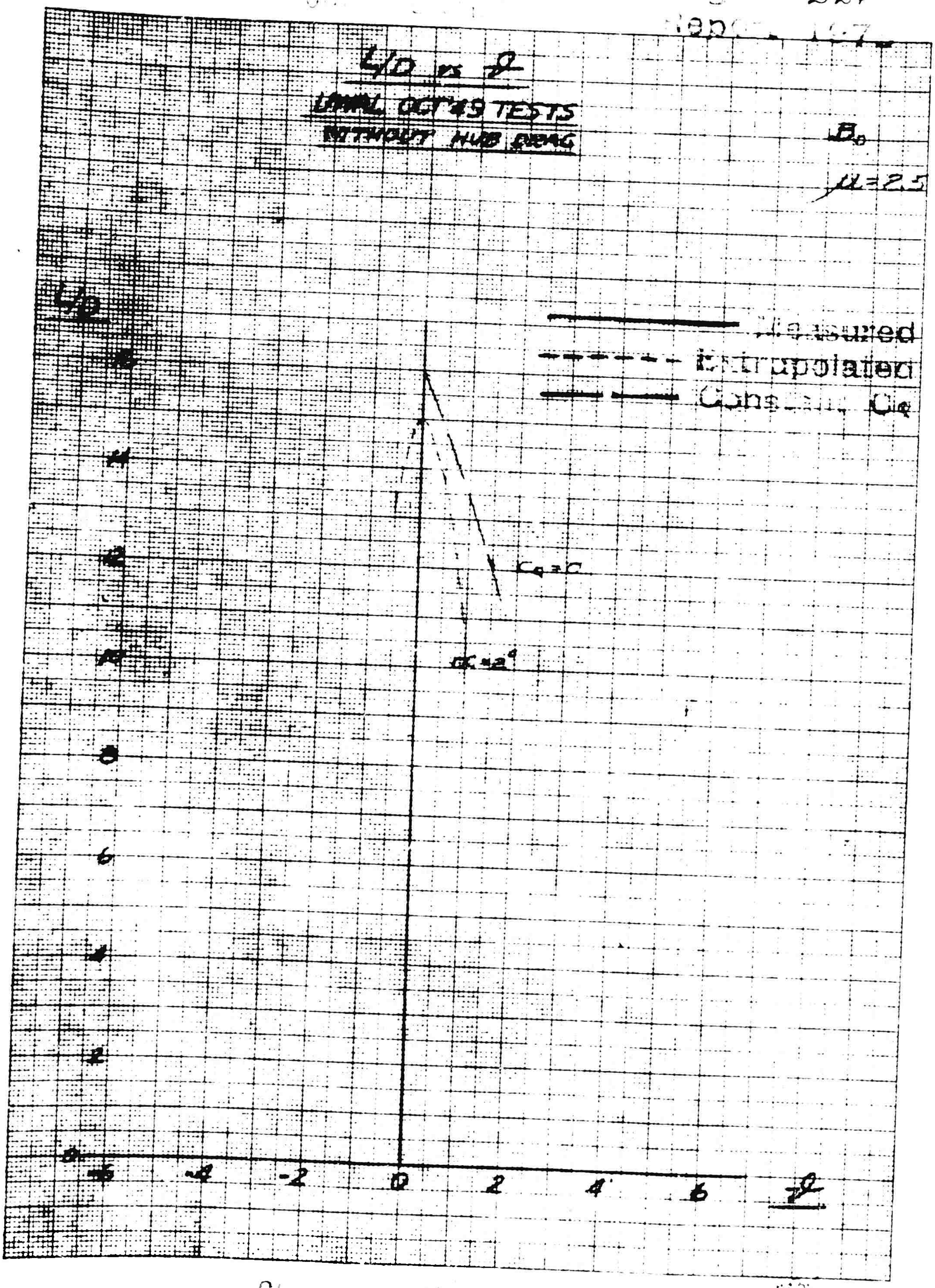


L/D vs θ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\mu = 1.5$
L/D
Measured
Extrapolated
Constant C_Q
$C_Q = 0$
$\alpha = 6°$
4°
2°
0°
16
14
12
10
8
6
4
2
0
-6
-4
-2
0
2
4
6
θ

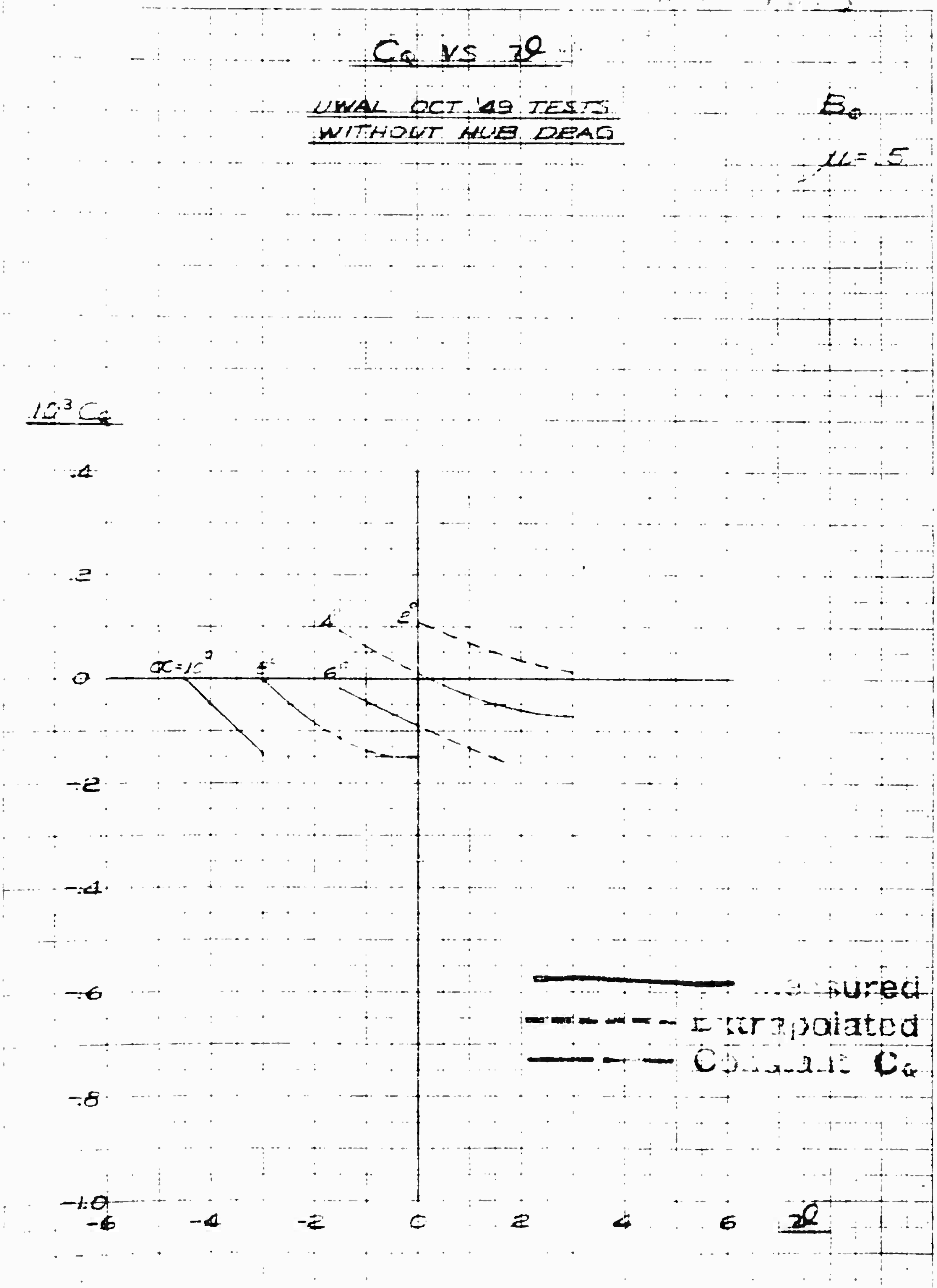


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

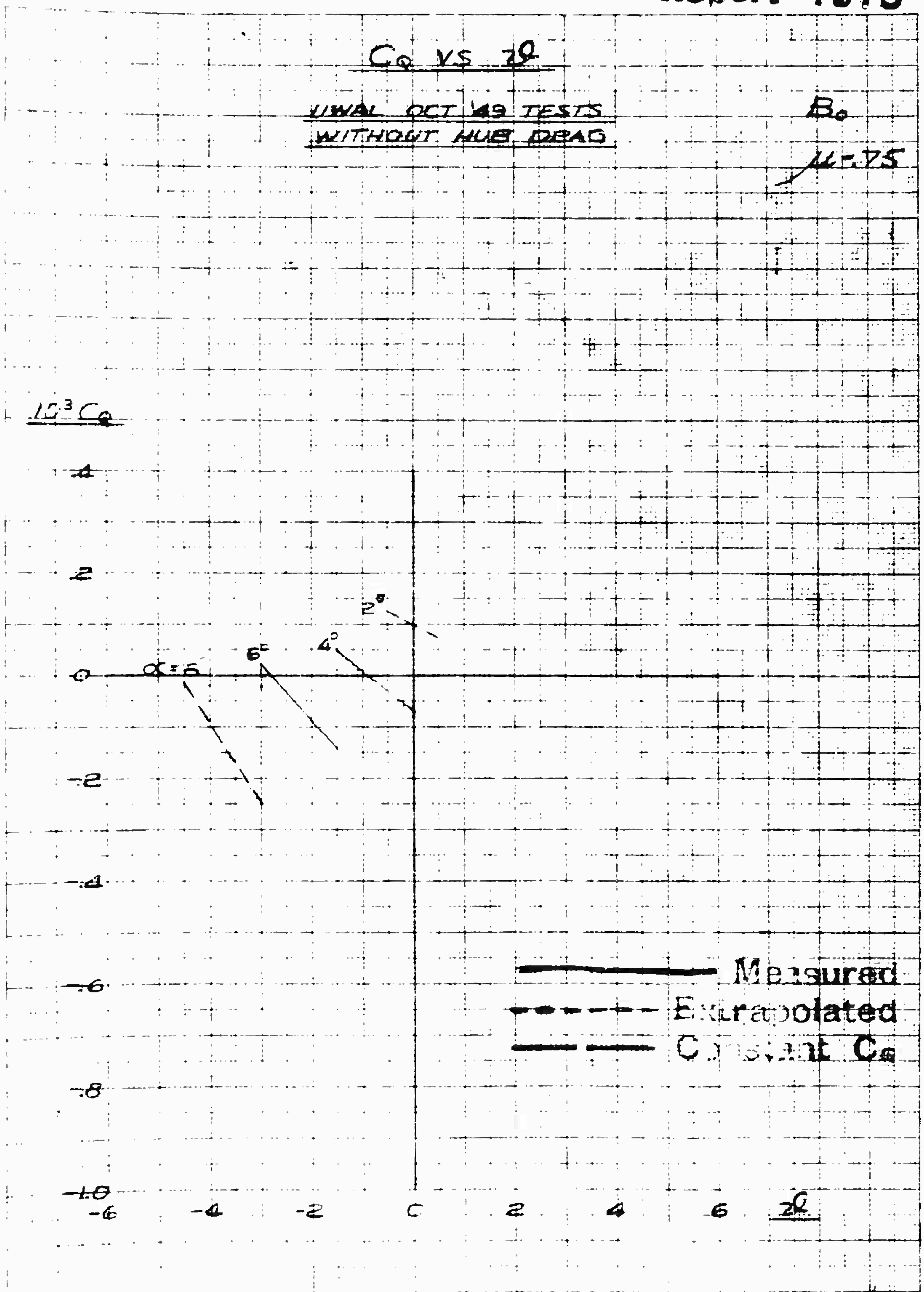
224



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



C_Q VS $\lambda\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\mu = .5$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\lambda\theta$
$\alpha = 10°$
8°
6°
4°
2°

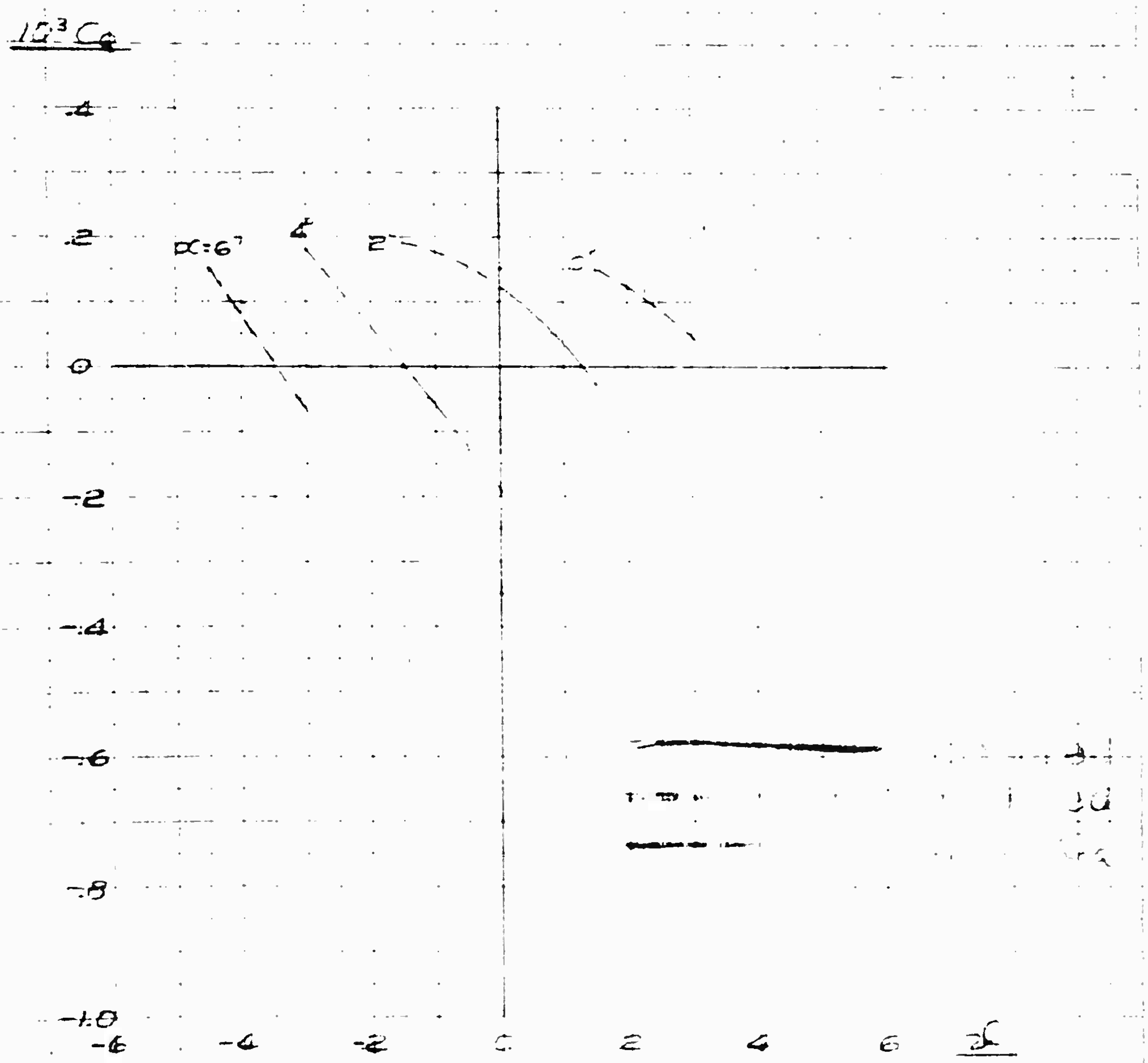

CQ VS 7θ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B0
μ=.75
10³ CQ
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
α=6
6°
4°
2°
Measured
Extrapolated
Constant CQ

C_Q VS θ

UWAL OCT '49 TESTS
WITHOUT HUB DRAG

β_0

$\mu = 1.0$

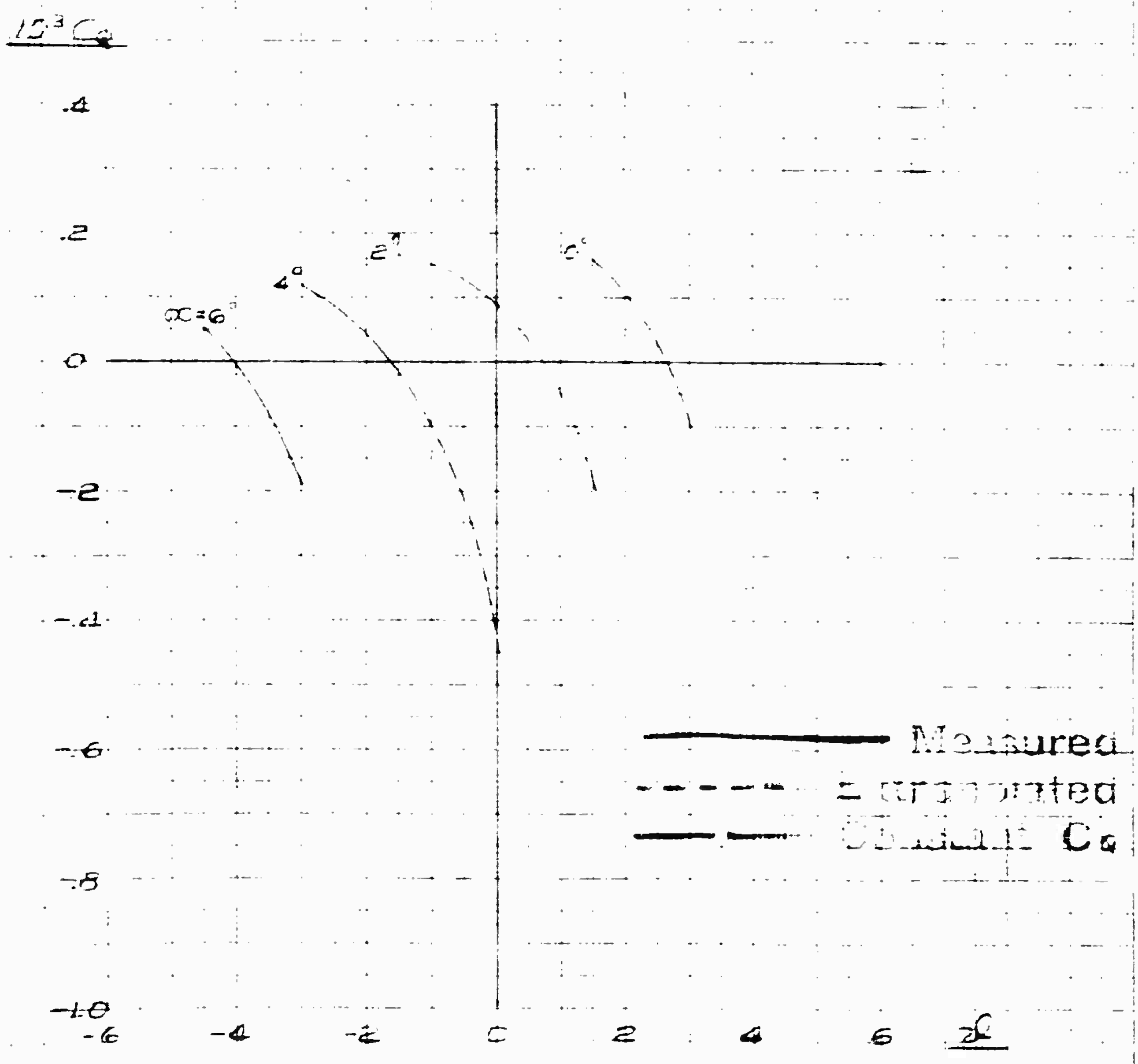


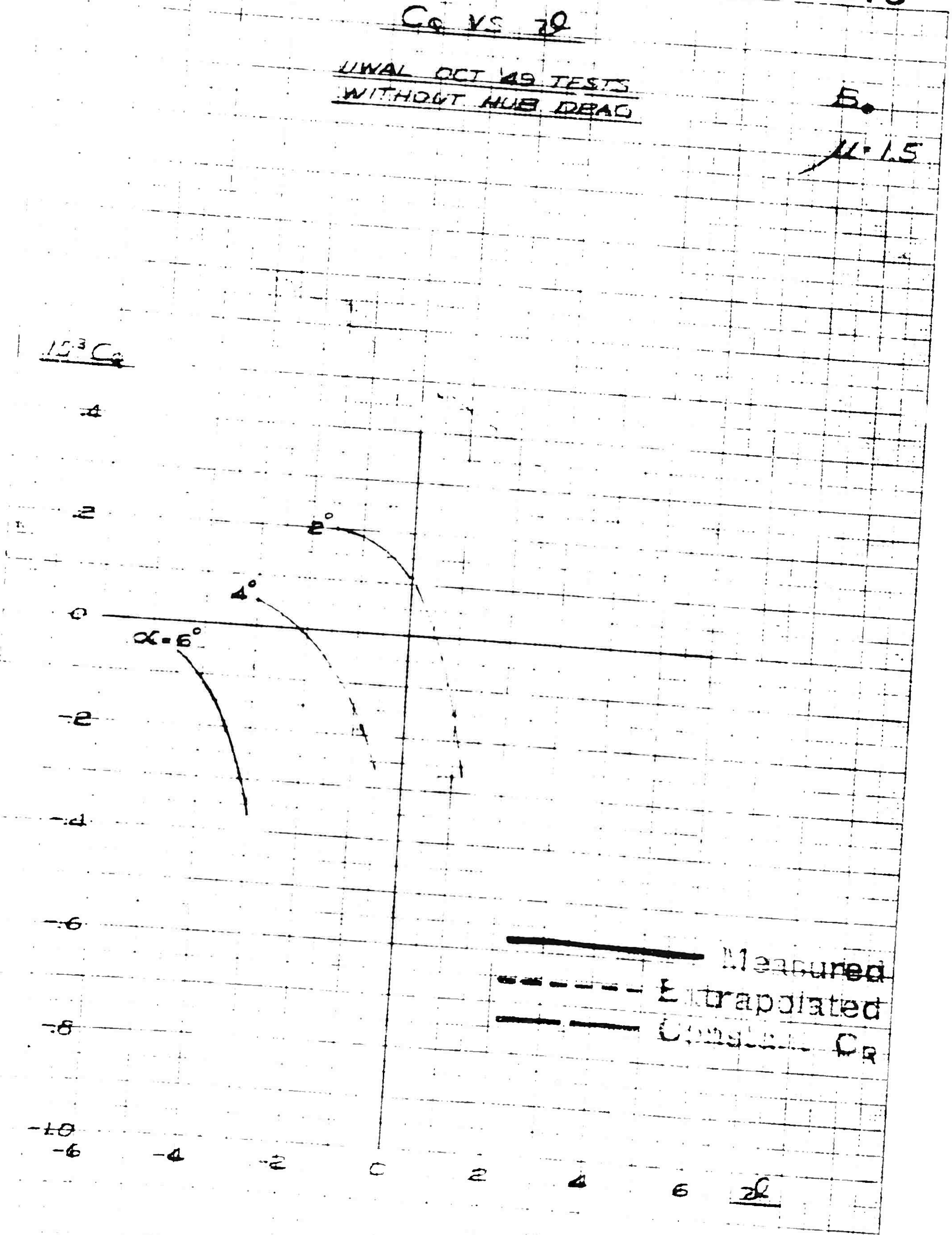
C_Q VS θ

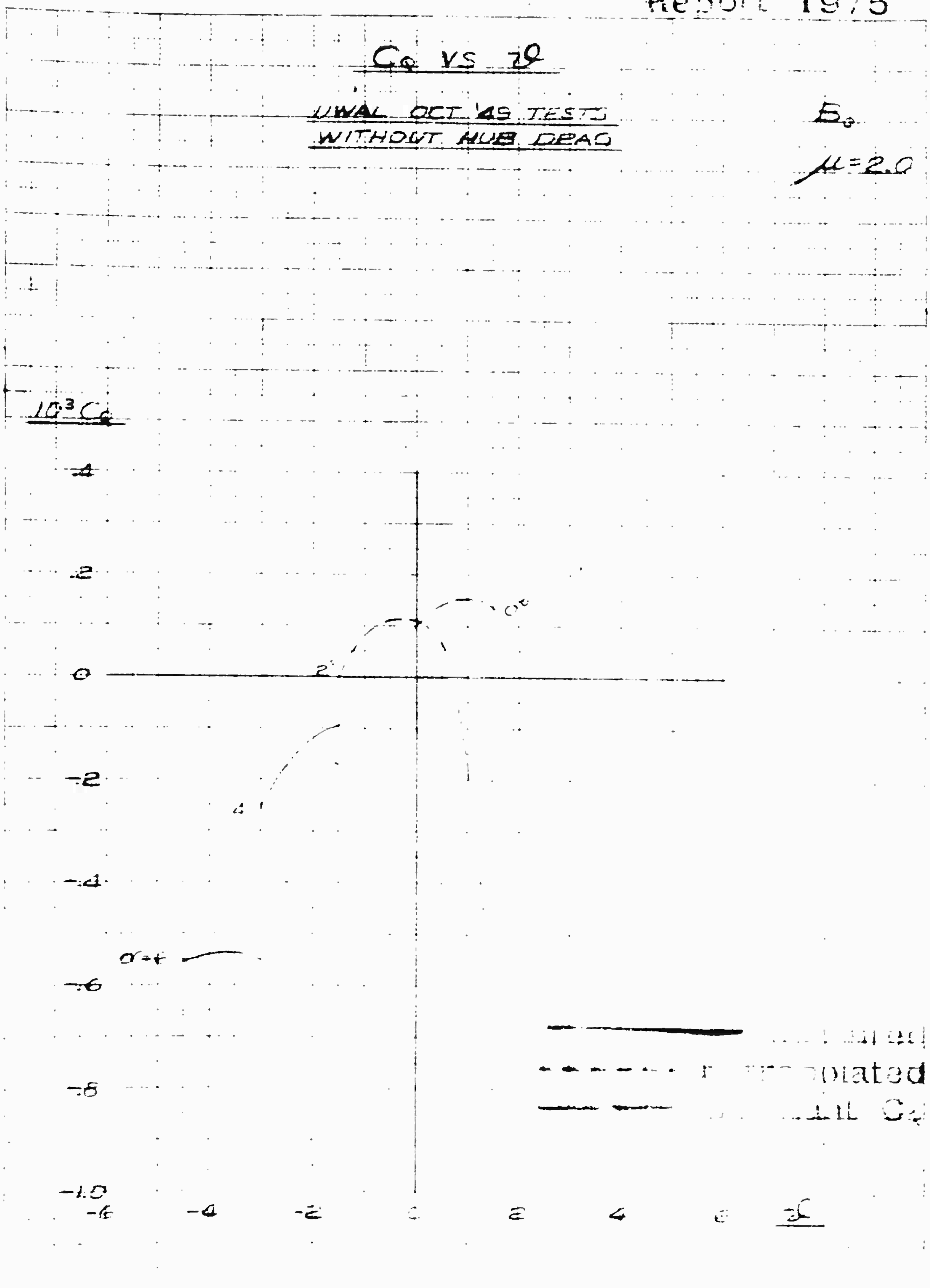
UWAL OCT '45 TESTS
WITHOUT HUB DRAG

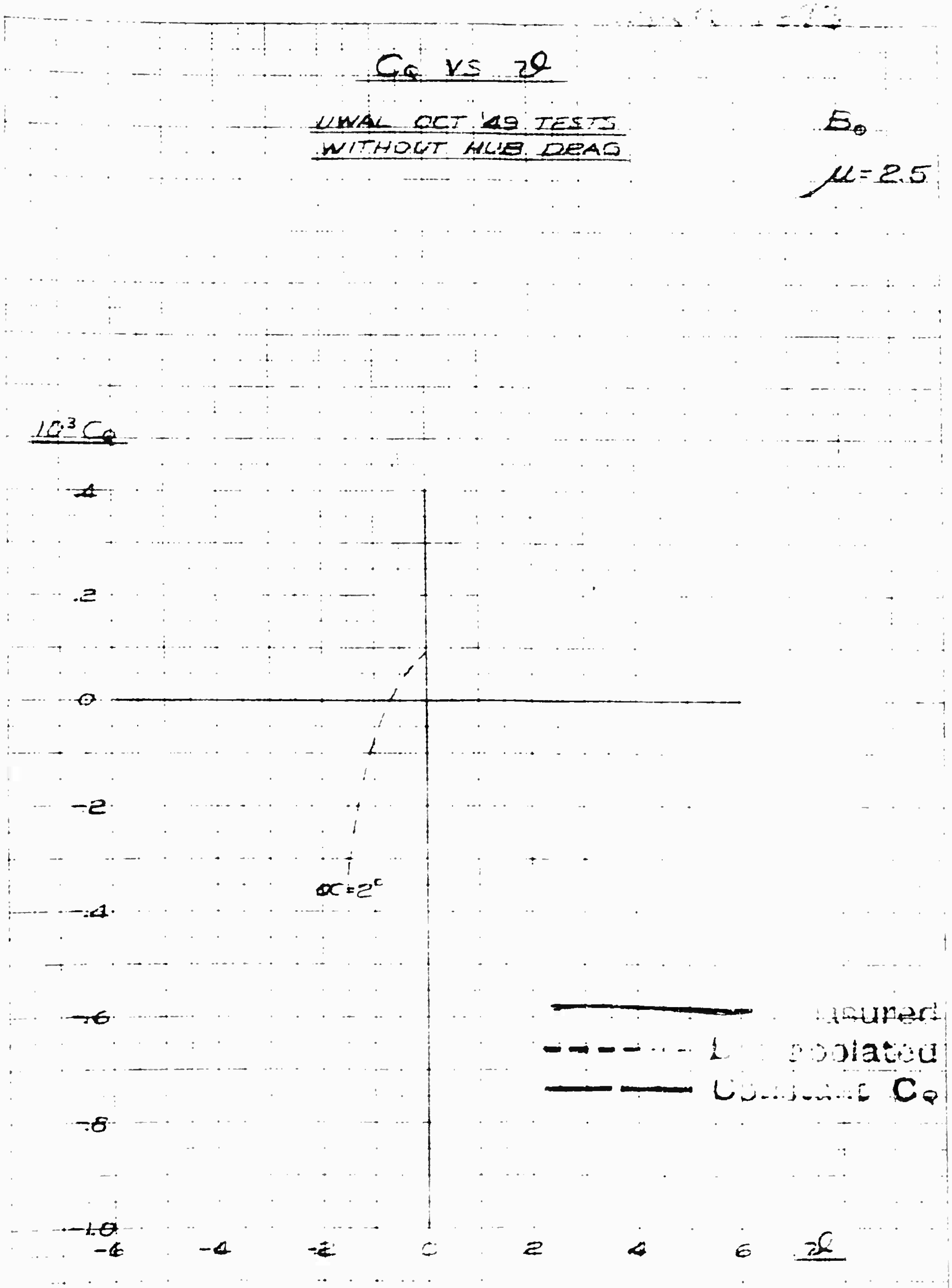
B_0

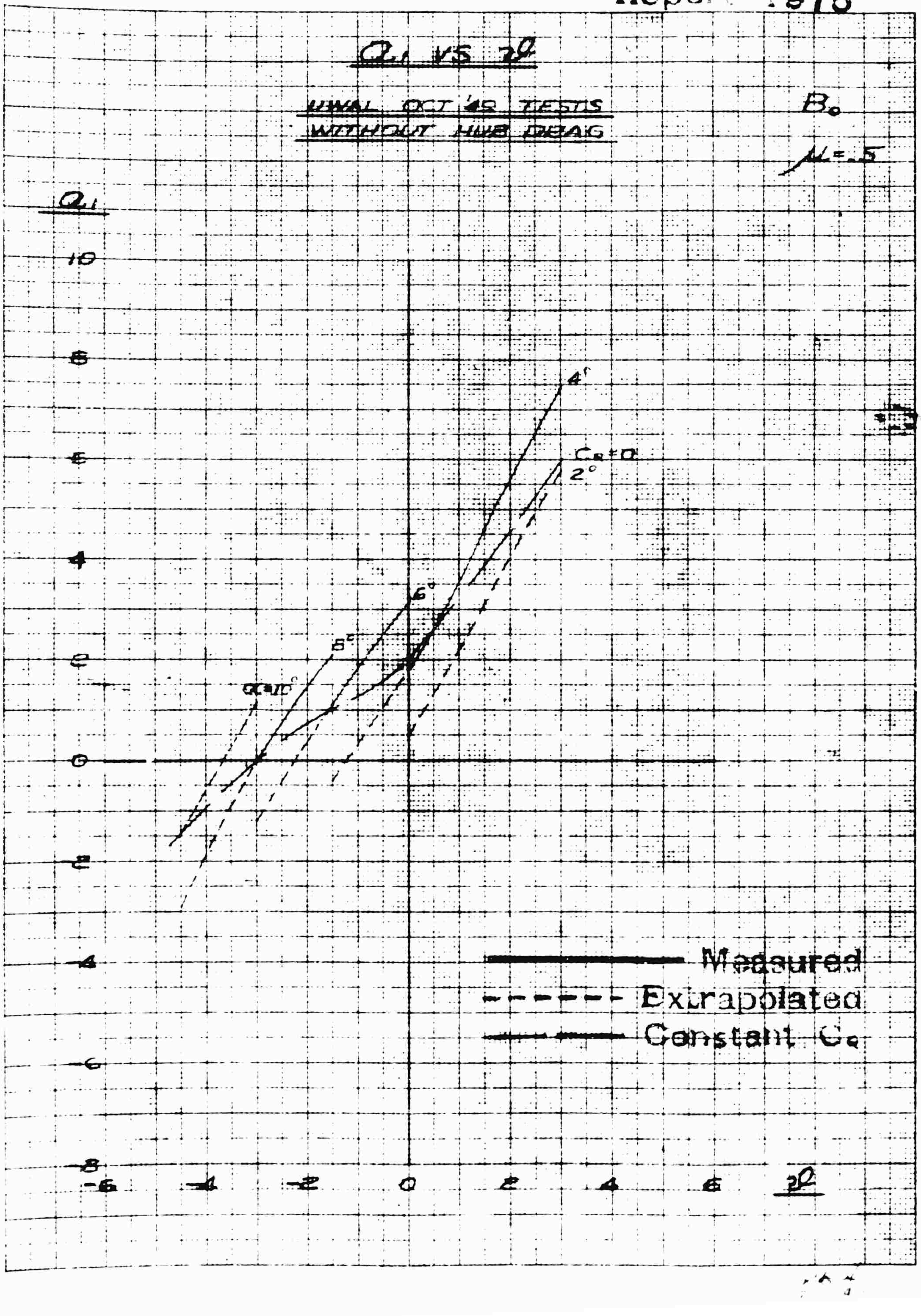
$\mu = 1.25$

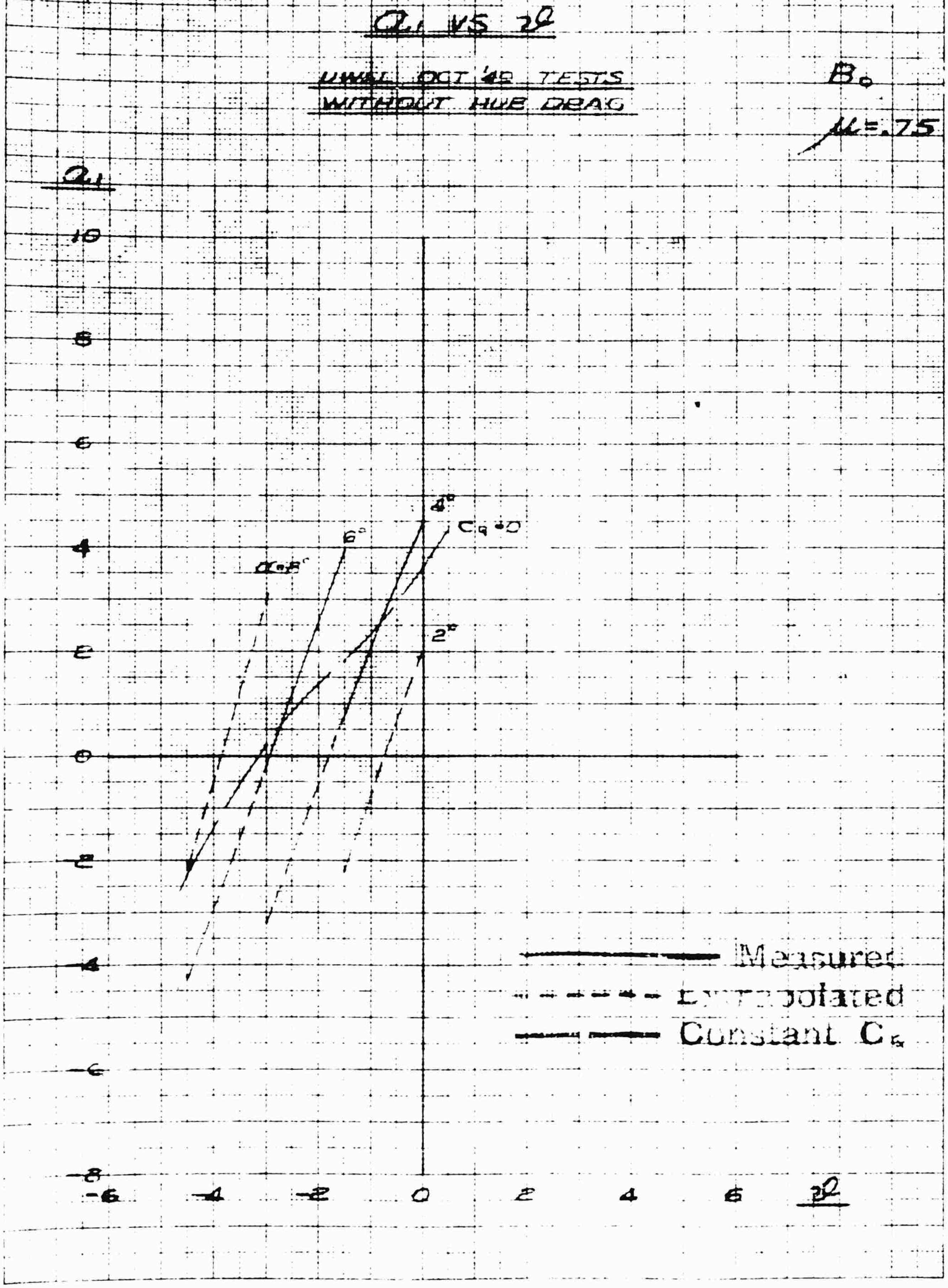



C_Q VS λ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
μ = 1.5
$10^3 C_Q$
4
2
0
-2
-4
-6
-8
-10
-6
-4
-2
0
2
4
6
λ
2°
4°
α = 6°
Measured
Extrapolated
Constant C_R

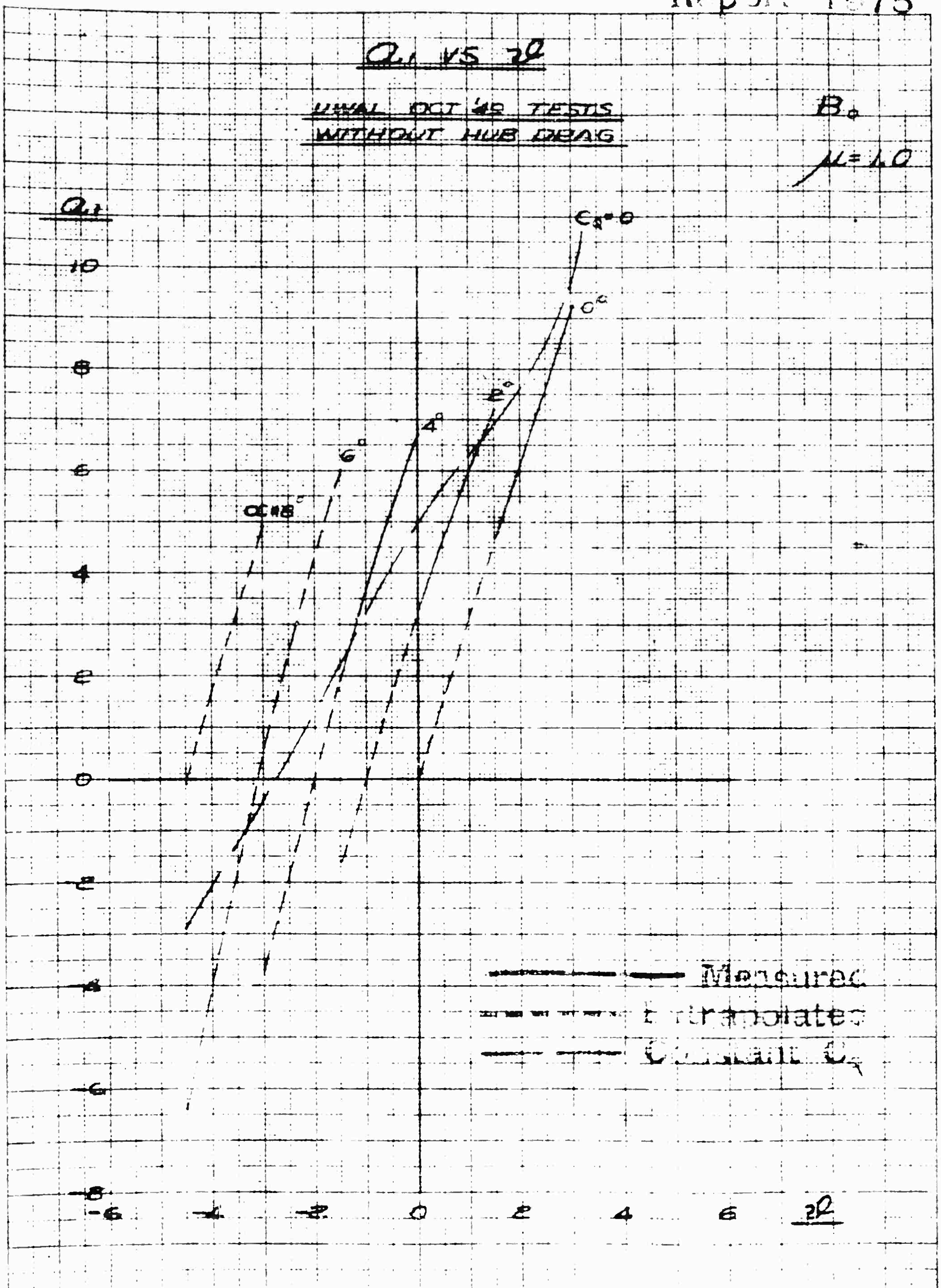

C_Q VS T_Q
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_3
$\mu = 2.0$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\sigma = 4$
...polated


C_Q VS $\tau\theta$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\mu = 2.5$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
$\tau\theta$
$\alpha = 2°$
Constant C_Q

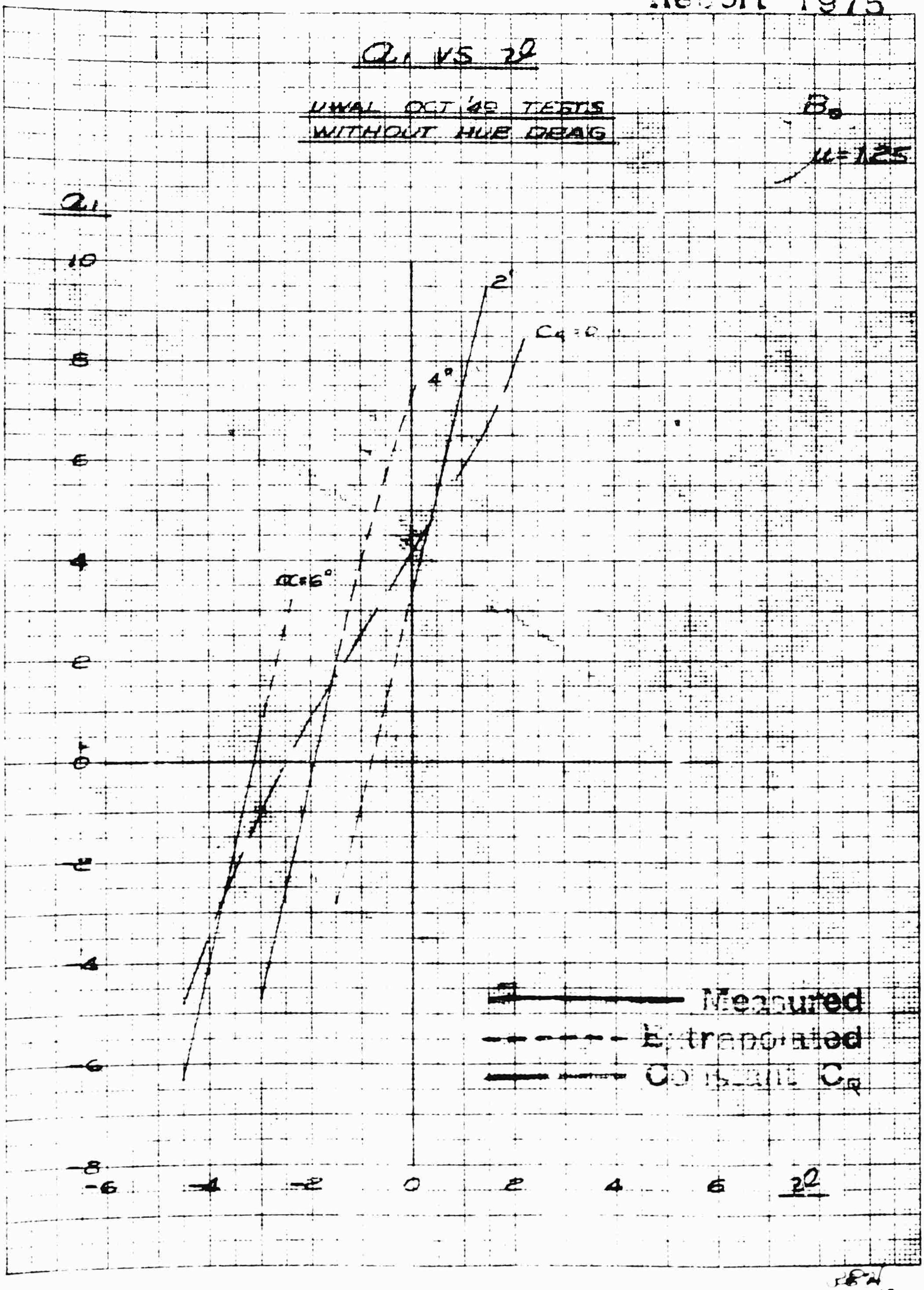

Q_1 VS η
UWAL OCT '42 TESTS
WITHOUT HUB DRAG
B_0
μ = .5
Q_1
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
η
4°
C_s=0
2°
6°
8°
α=10°
Measured
Extrapolated
Constant C_s



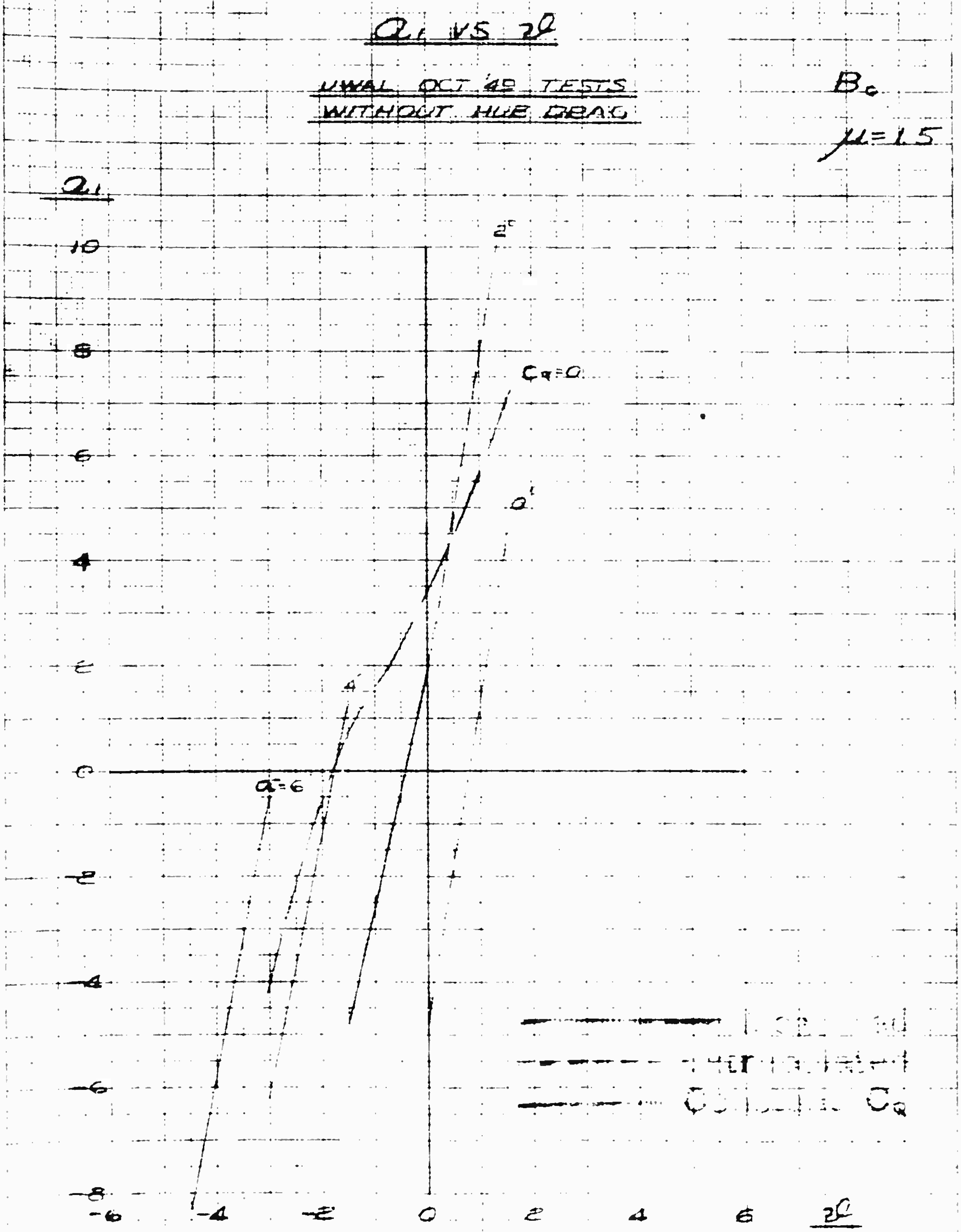
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

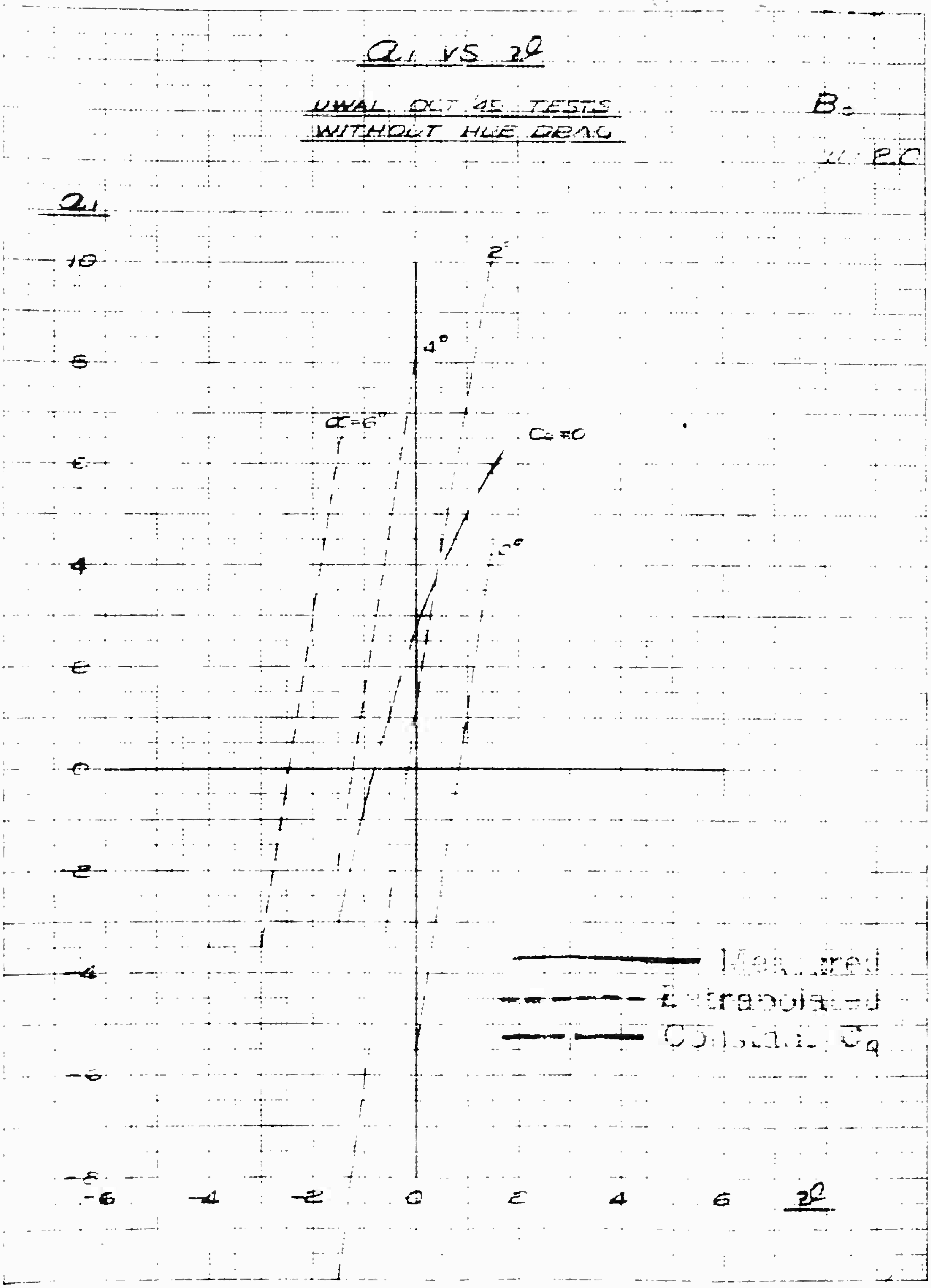


KEUFFEL & ESSER CO.
No. 359-11 Millimeters

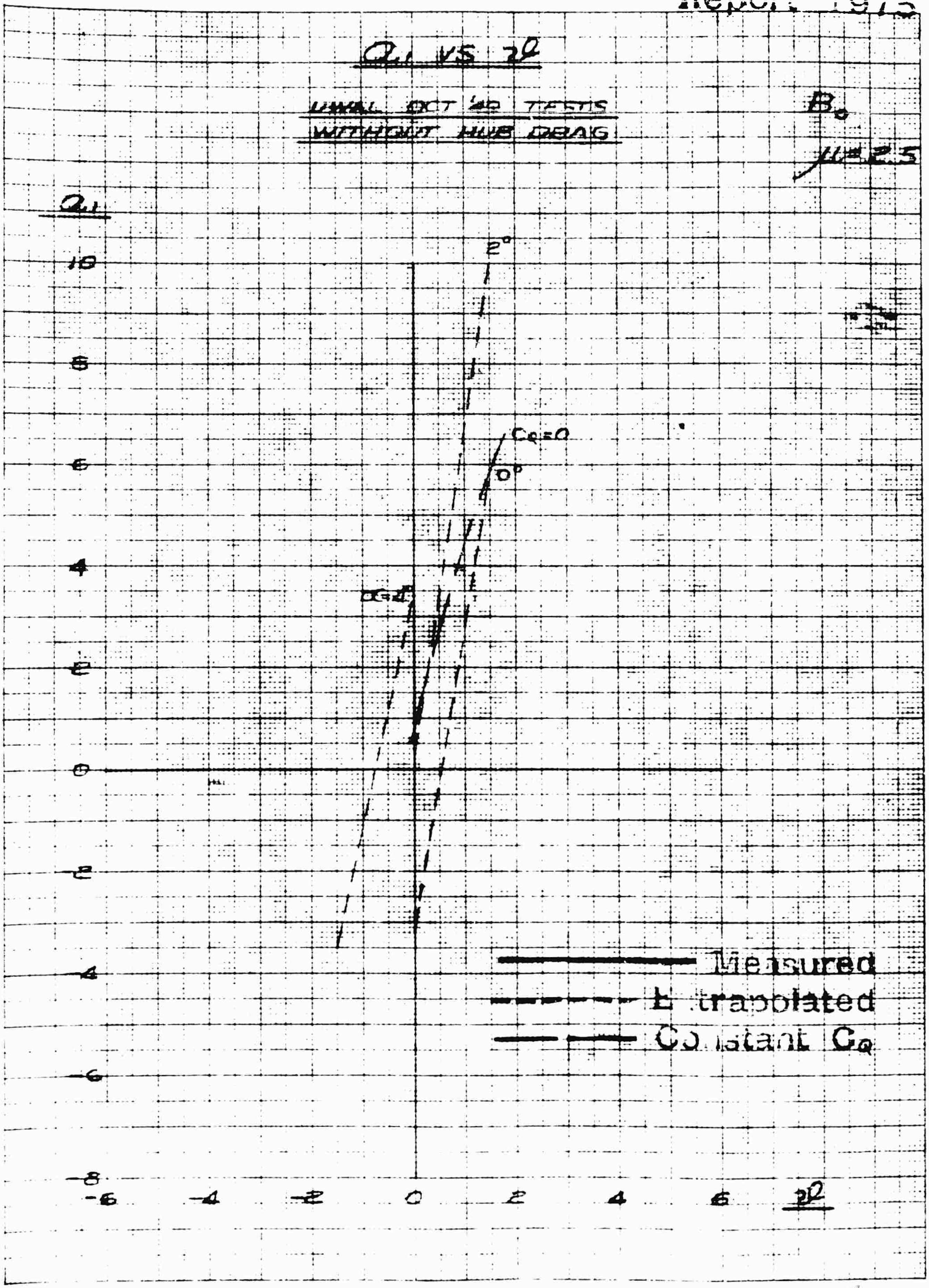

Q₁ VS ϑ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B₅
μ=.125
Q₁
10
8
6
4
2
0
-2
-4
-6
-8
2°
C_Q=0
4°
α=6°
Measured
Extrapolated
Constant C_Q
-6
-4
-2
0
2
4
6
ϑ

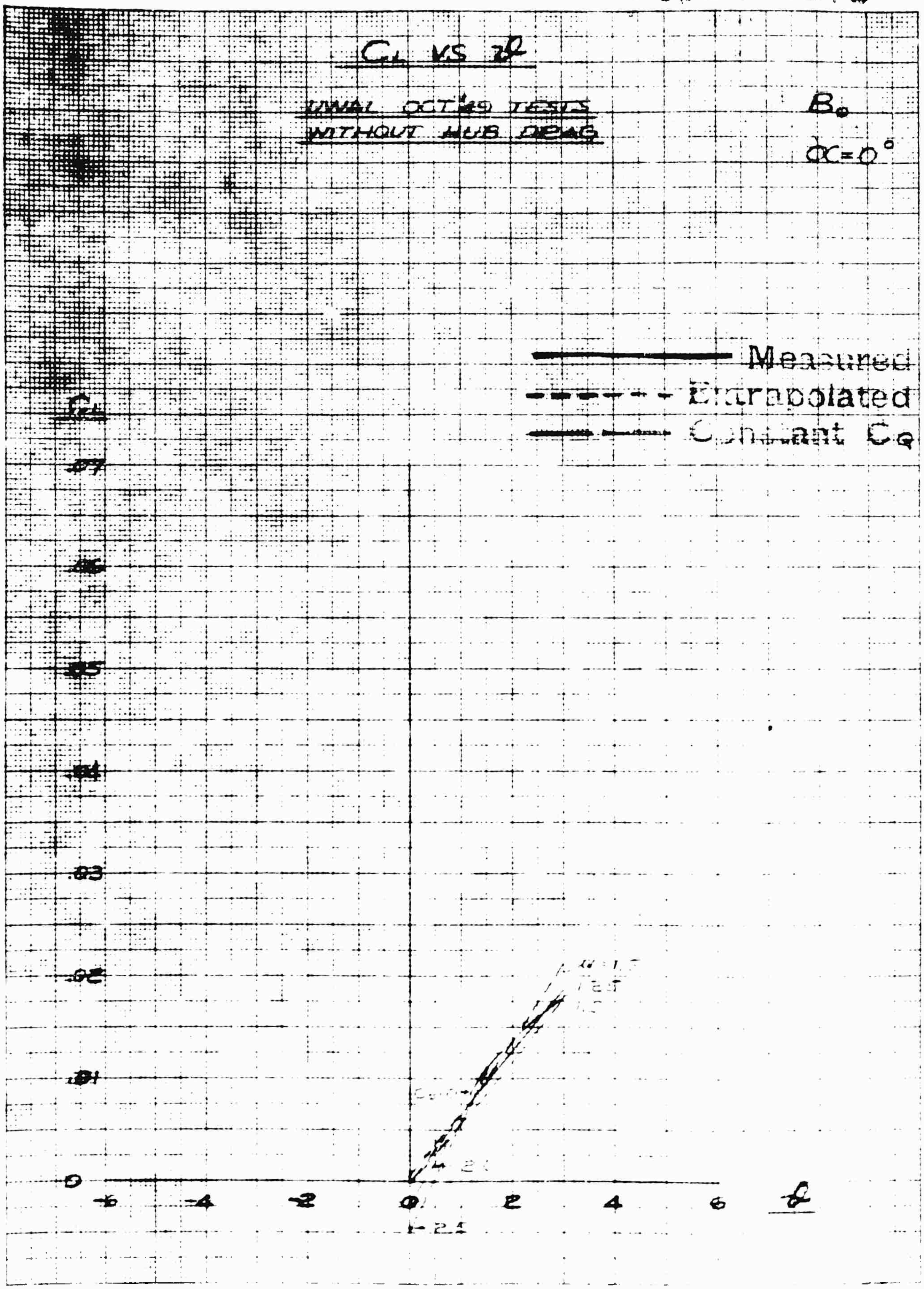
12-17-49

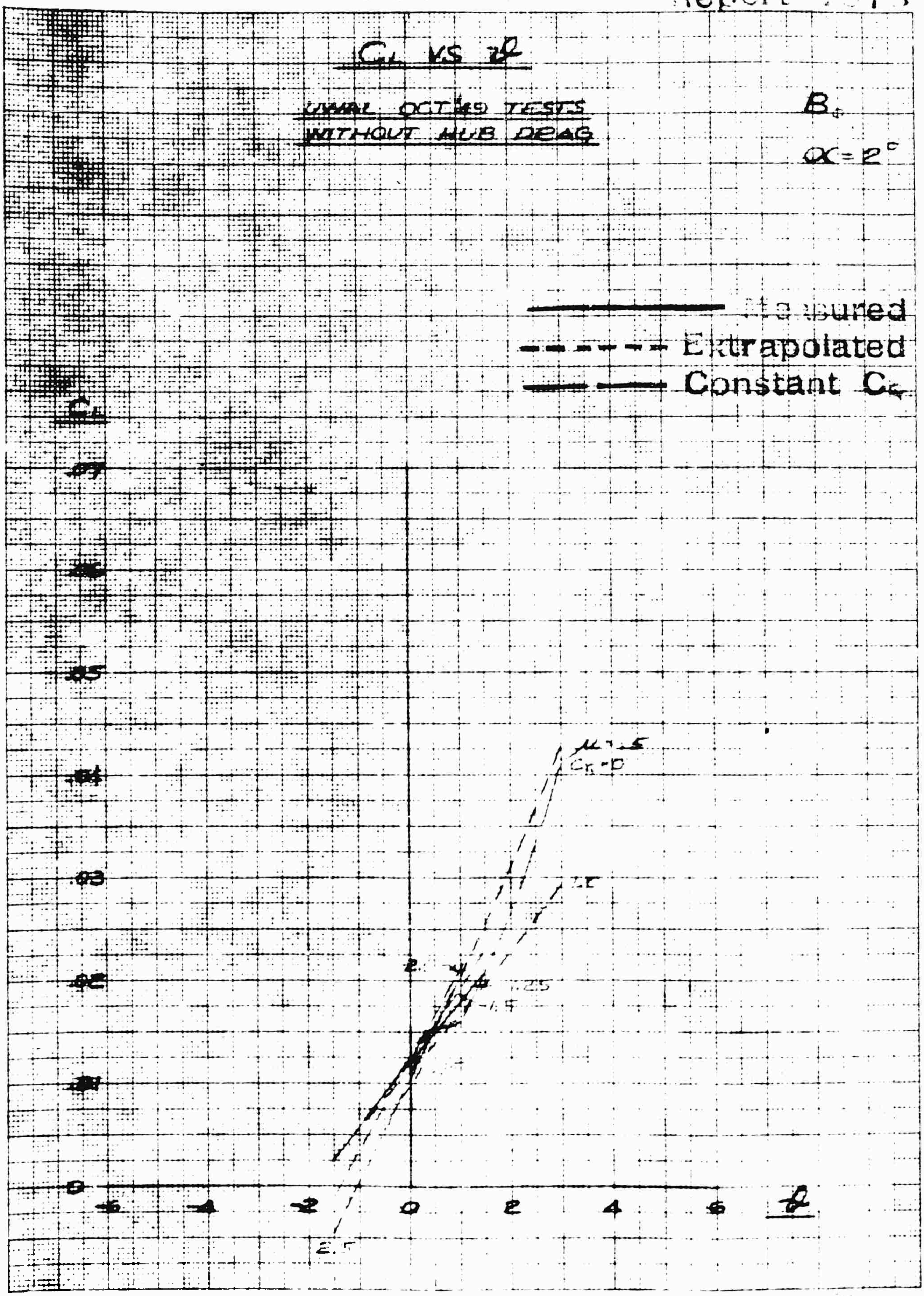

a_1 VS θ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_c
$\mu = 1.5$
a_1
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
θ
2°
$C_Q = 0$
0°
4°
$\alpha = 6$



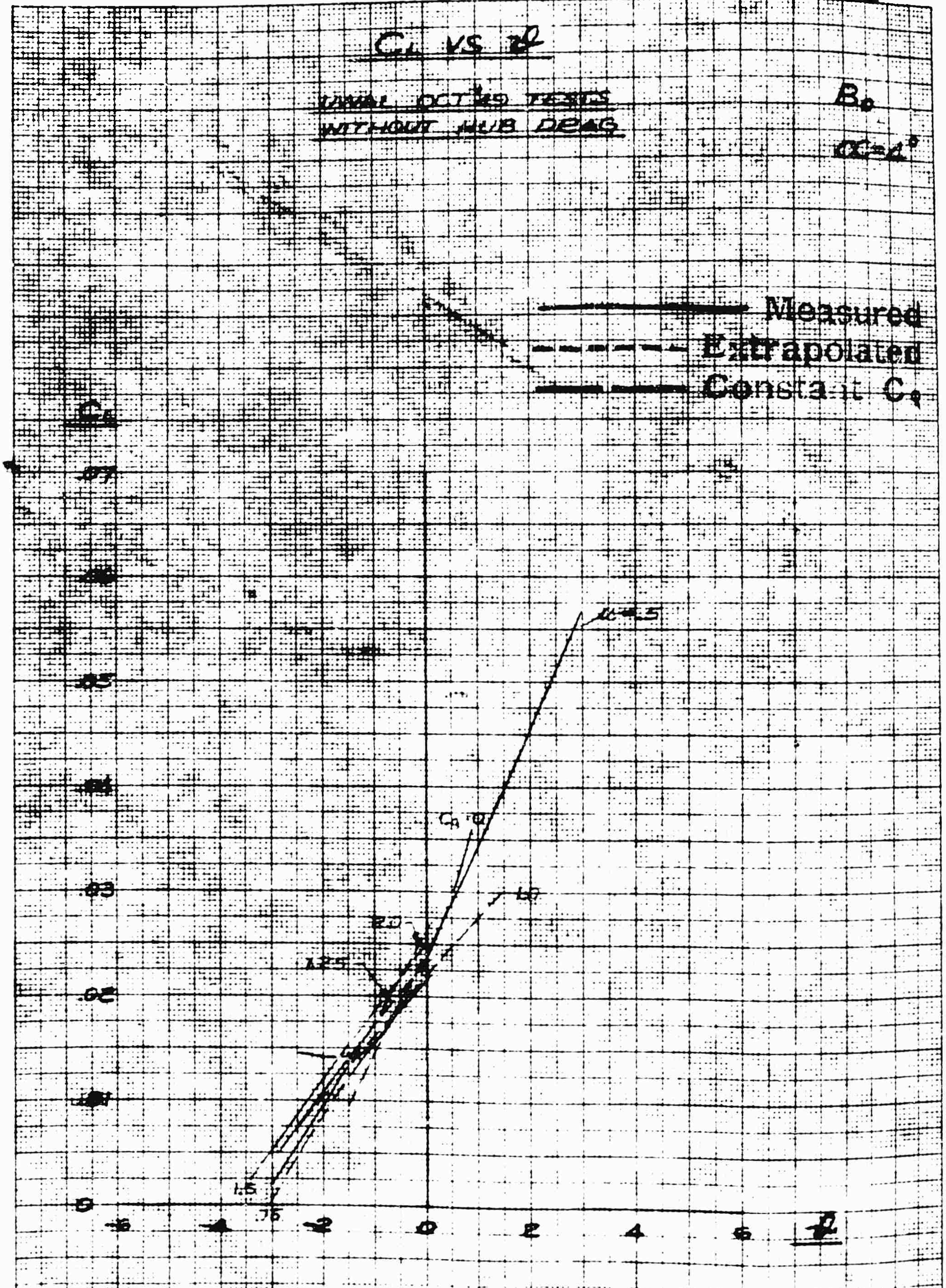
a_1 VS 2θ
UWAL OCT '45 TESTS
WITHOUT HUB DRAG
B
a_1
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
2θ
2°
4°
α=6°
Measured
Extrapolated


Q_1 VS λ^ℓ
UWAL OCT '42 TESTS
WITHOUT HUB DRAG
B_c
$\mu = 2.5$
Q_1
10
8
6
4
2
0
-2
-4
-6
-8
$2°$
$C_Q=0$
$0°$
-6
-4
-2
0
2
4
6
λ^ℓ
Measured
Extrapolated
Constant C_Q

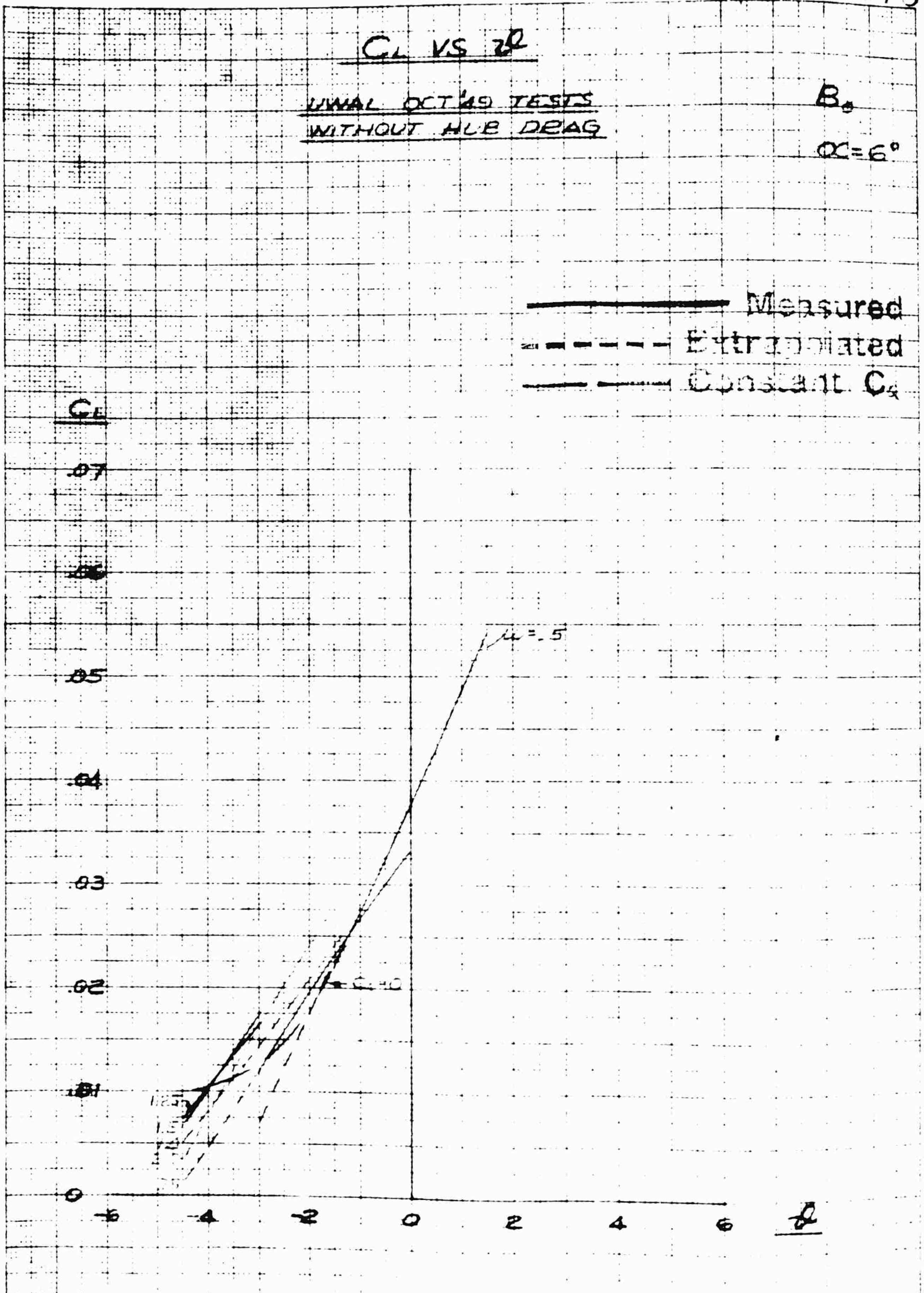

C_L VS ϕ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\alpha = 0°$
Measured
Extrapolated
Constant C_Q
C_L
.07
.06
.05
.04
.03
.02
.01
0
-6
-4
-2
0
2
4
6
ϕ



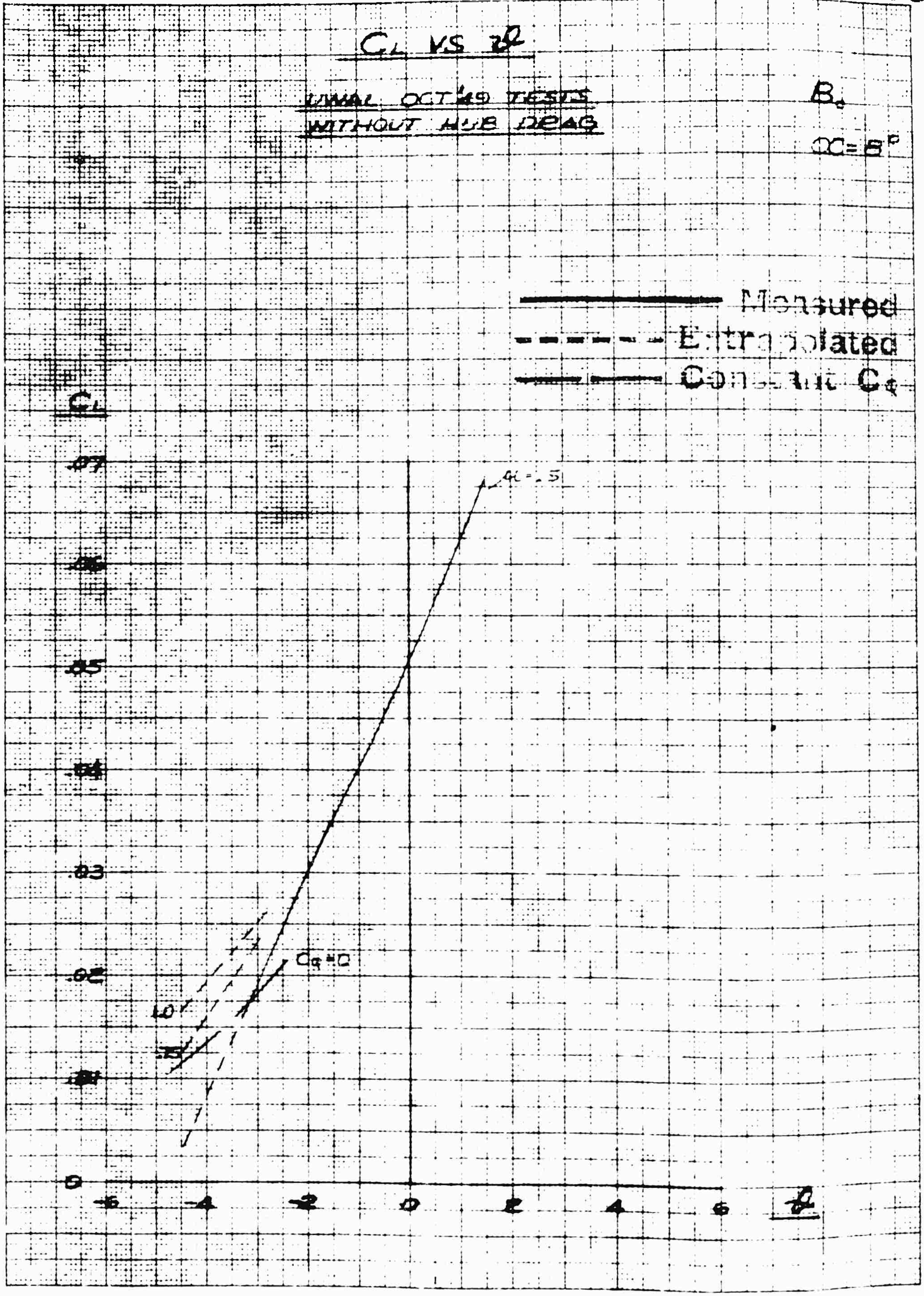
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.

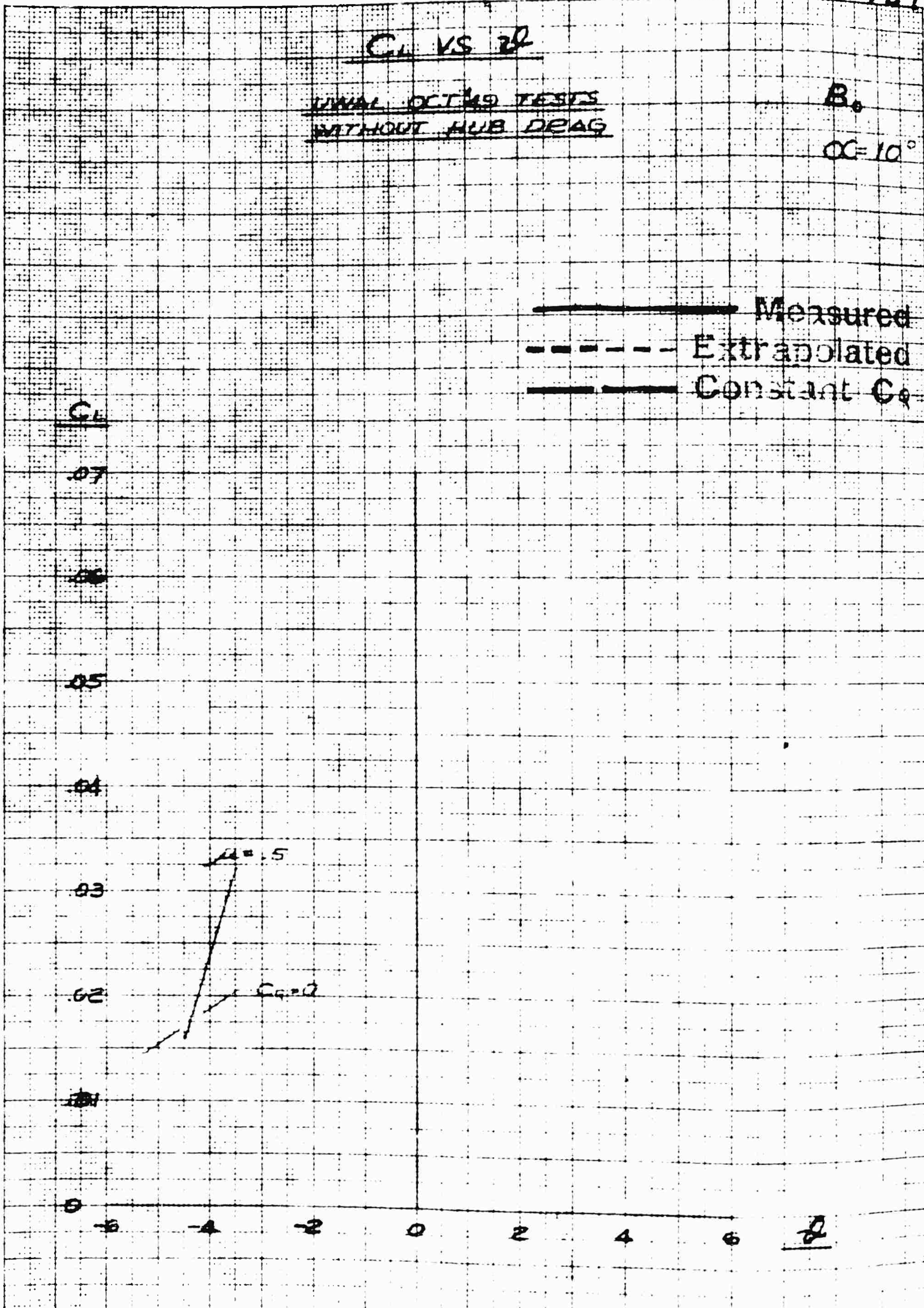


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

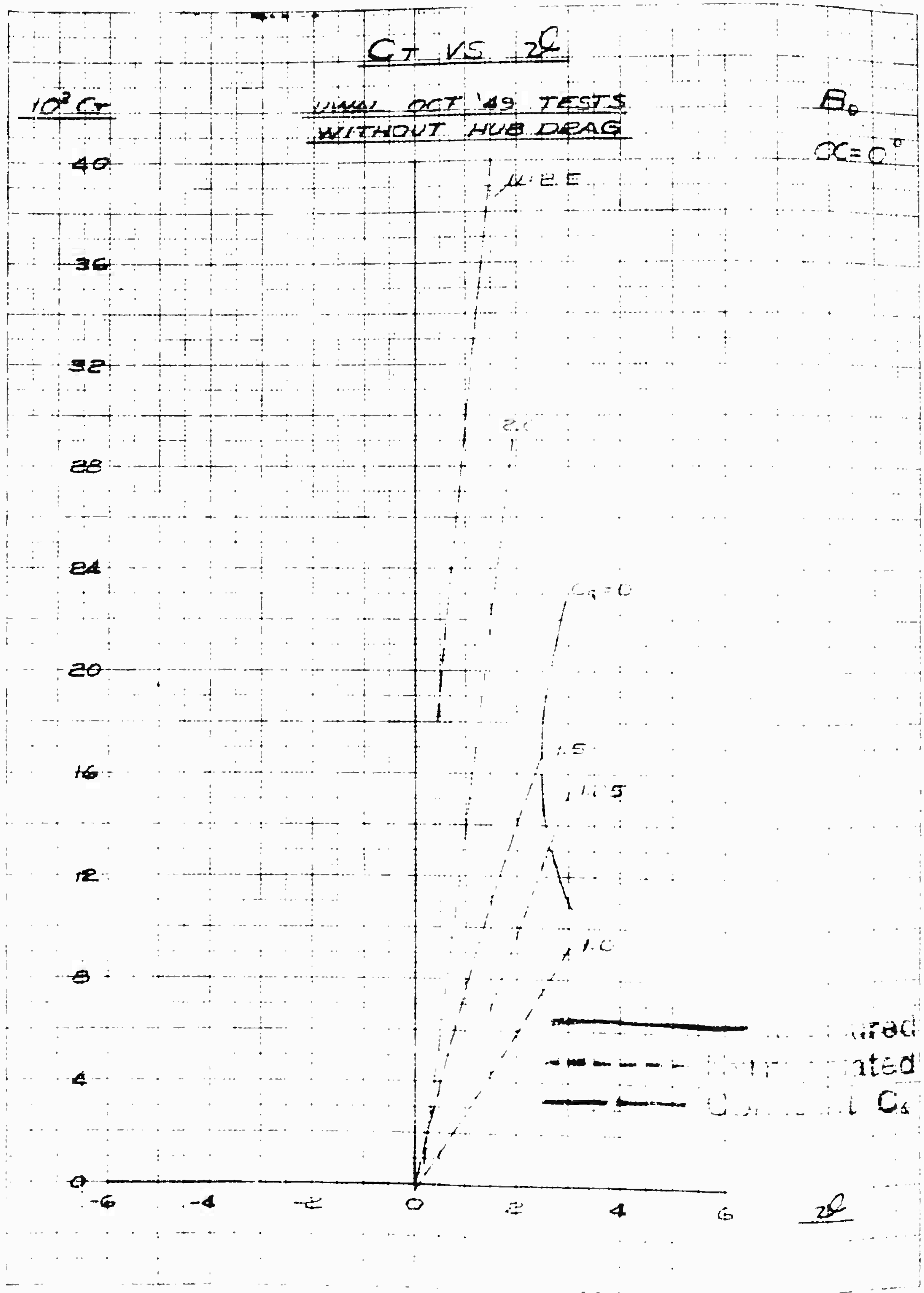
CONFIDENTIAL

Report 1978

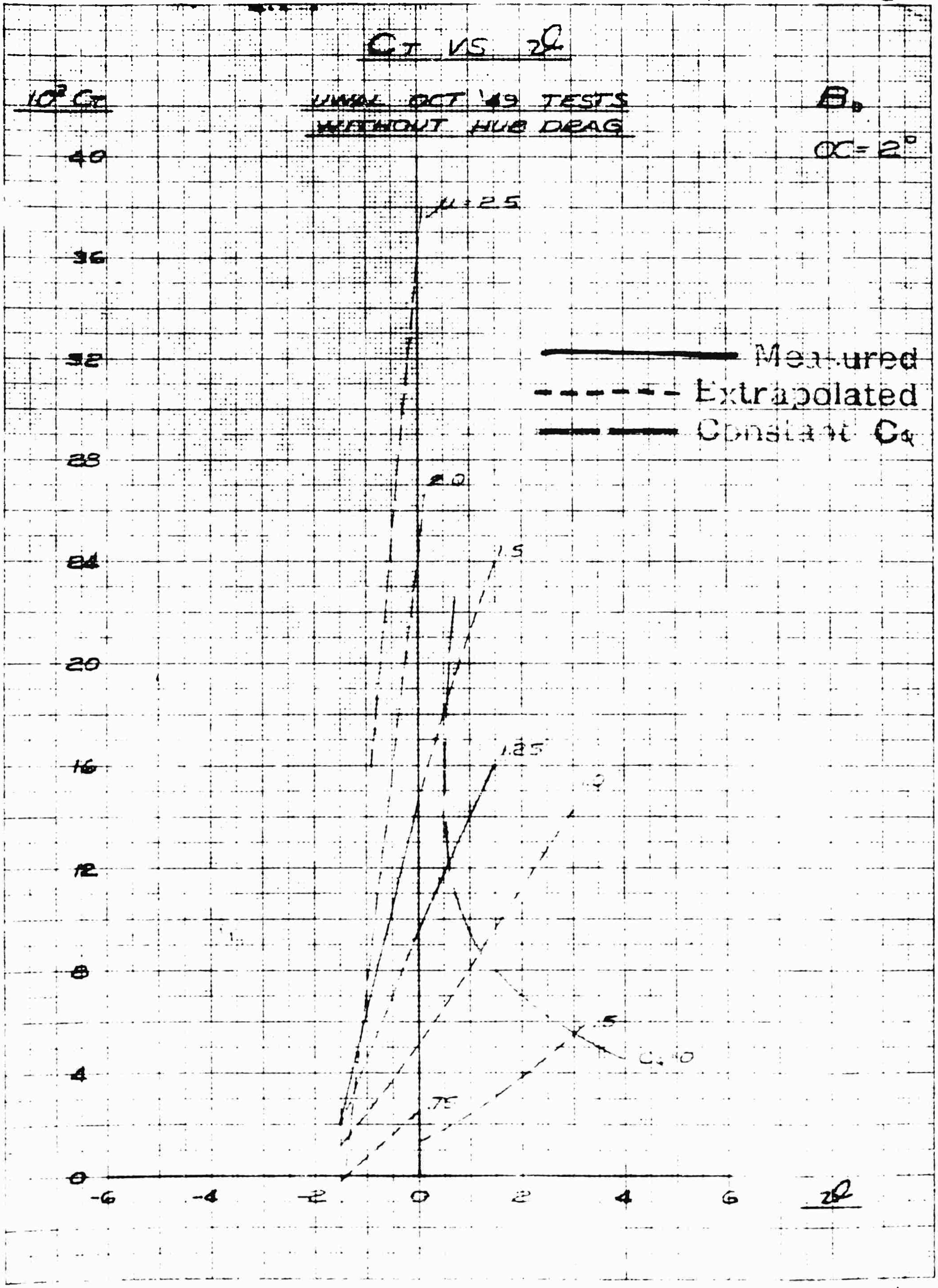
244



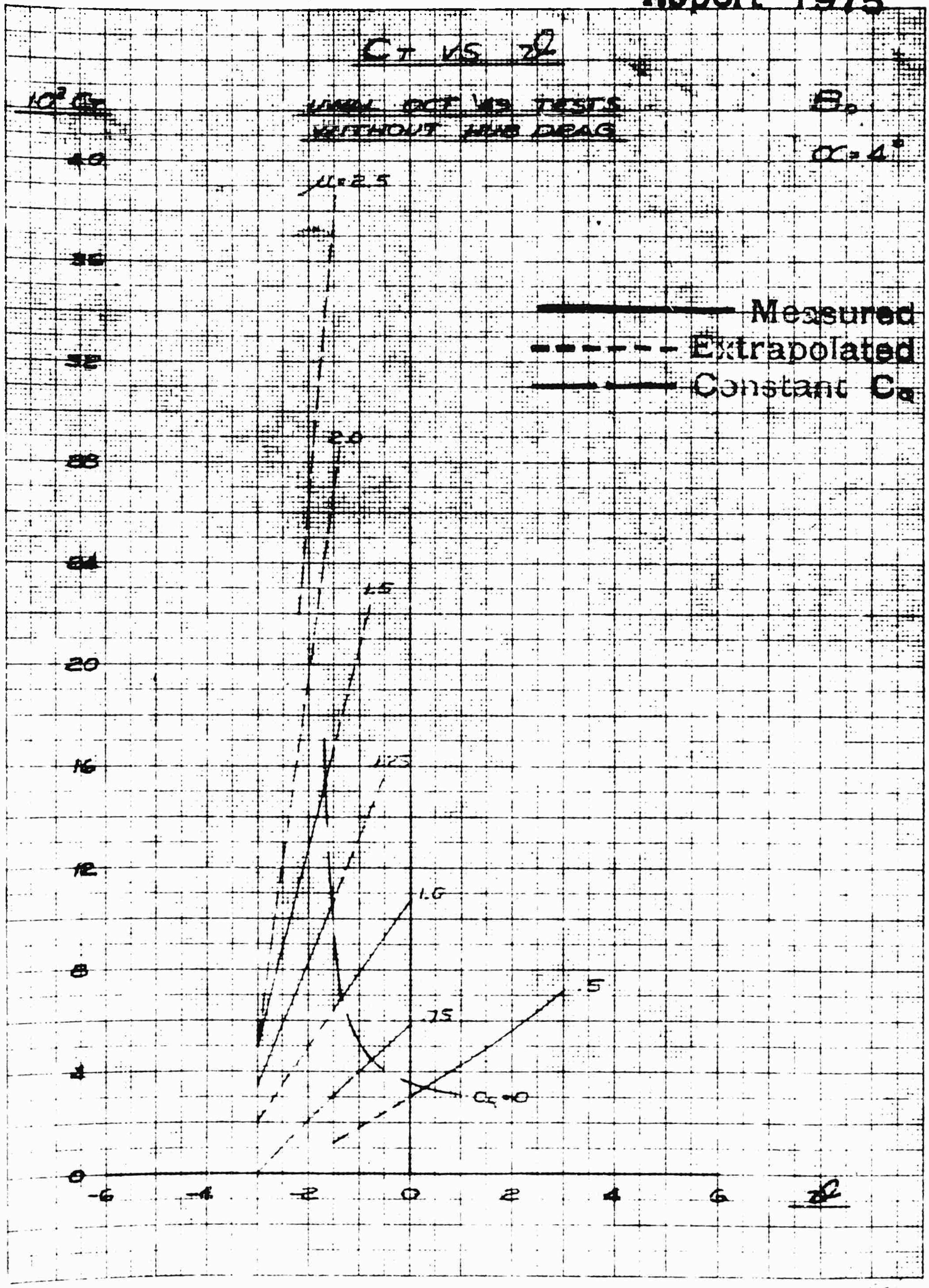
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy


C_T VS 2θ
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\alpha = 0°$
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
2θ
μ=2.5
2.0
C_Q=0
1.5
1.25
1.0
...ured
...nted
...t C_Q

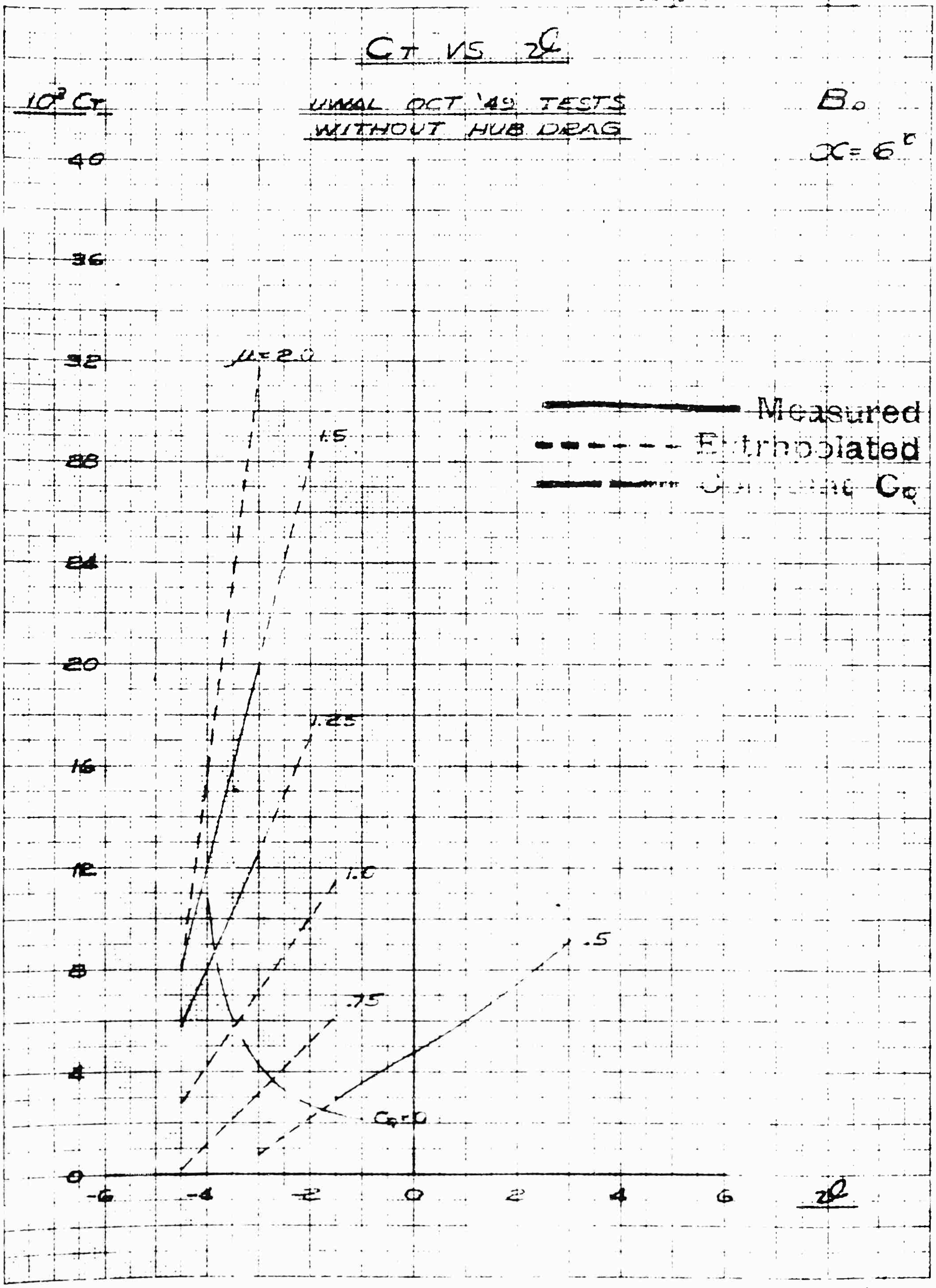
CONFIDENTIAL



CONFIDENTIAL



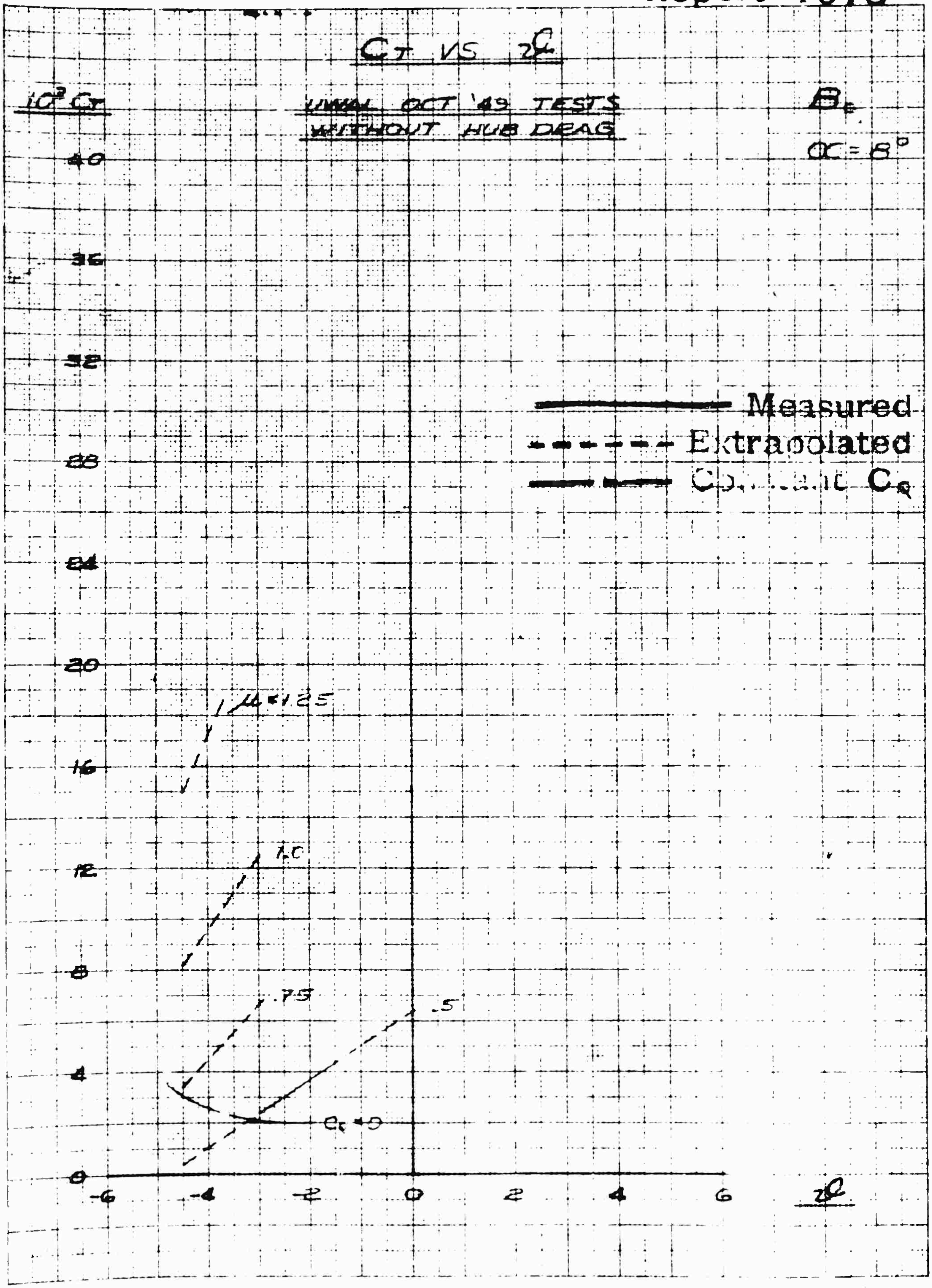
CONF... Report

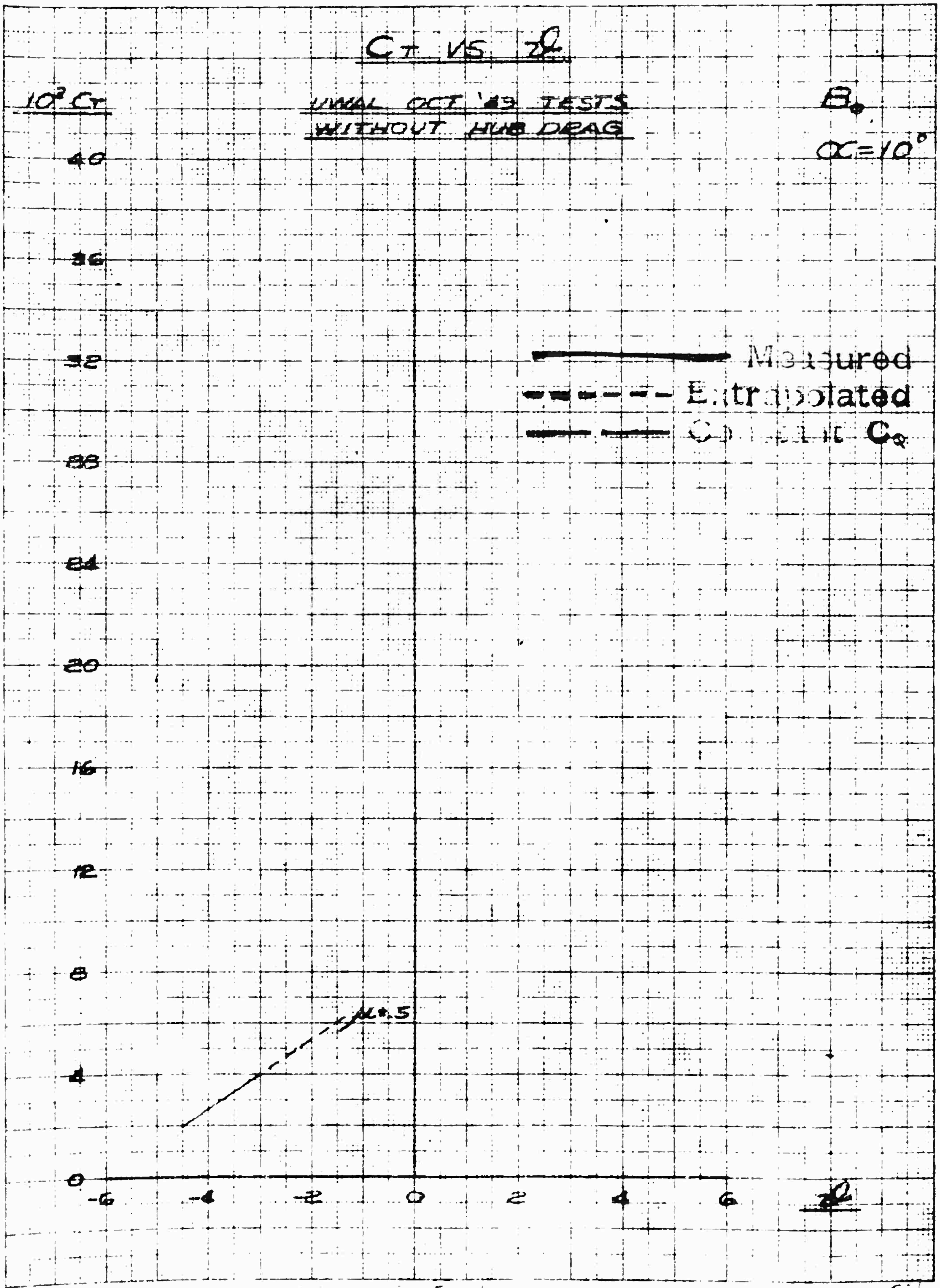


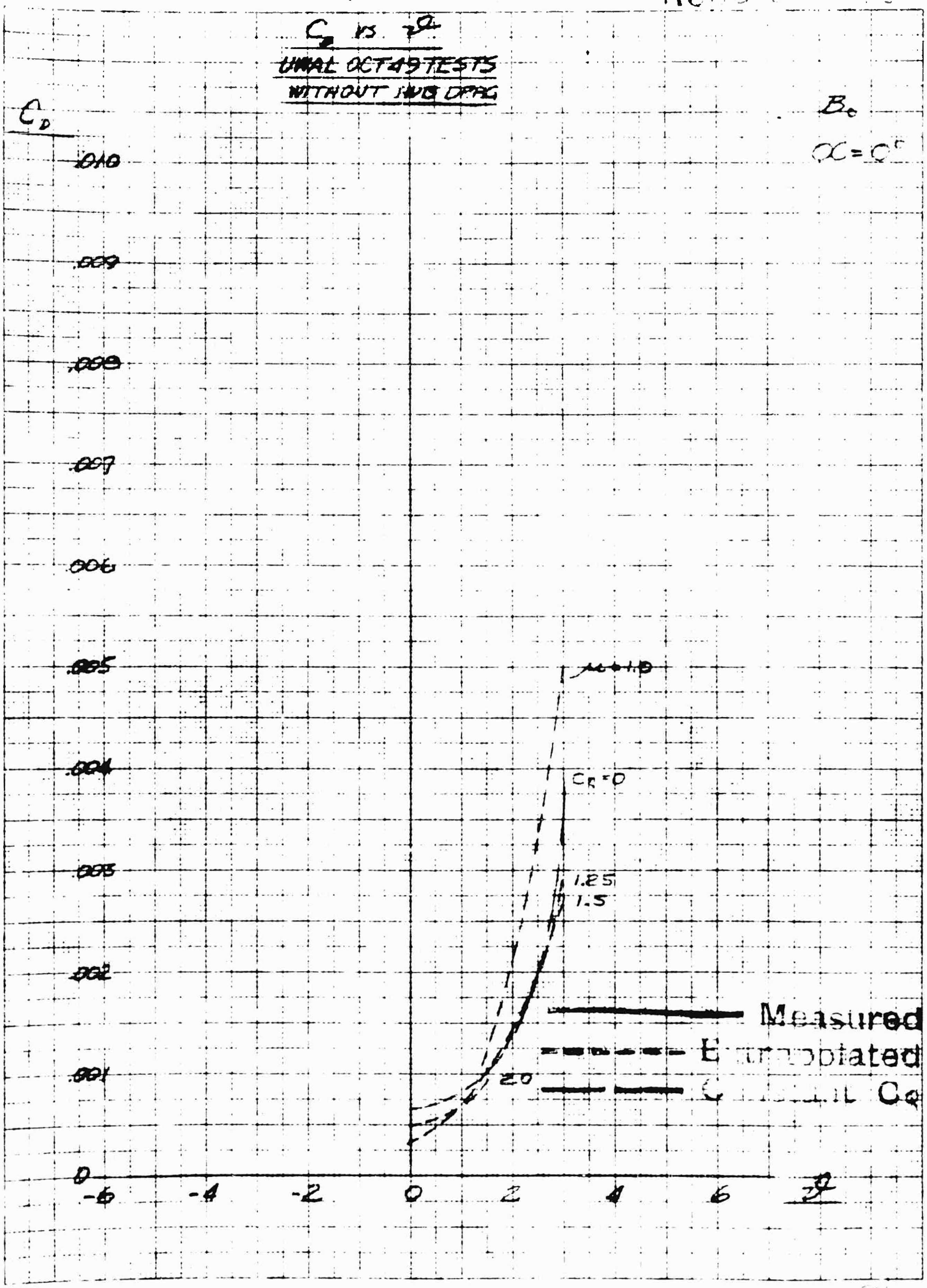
KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

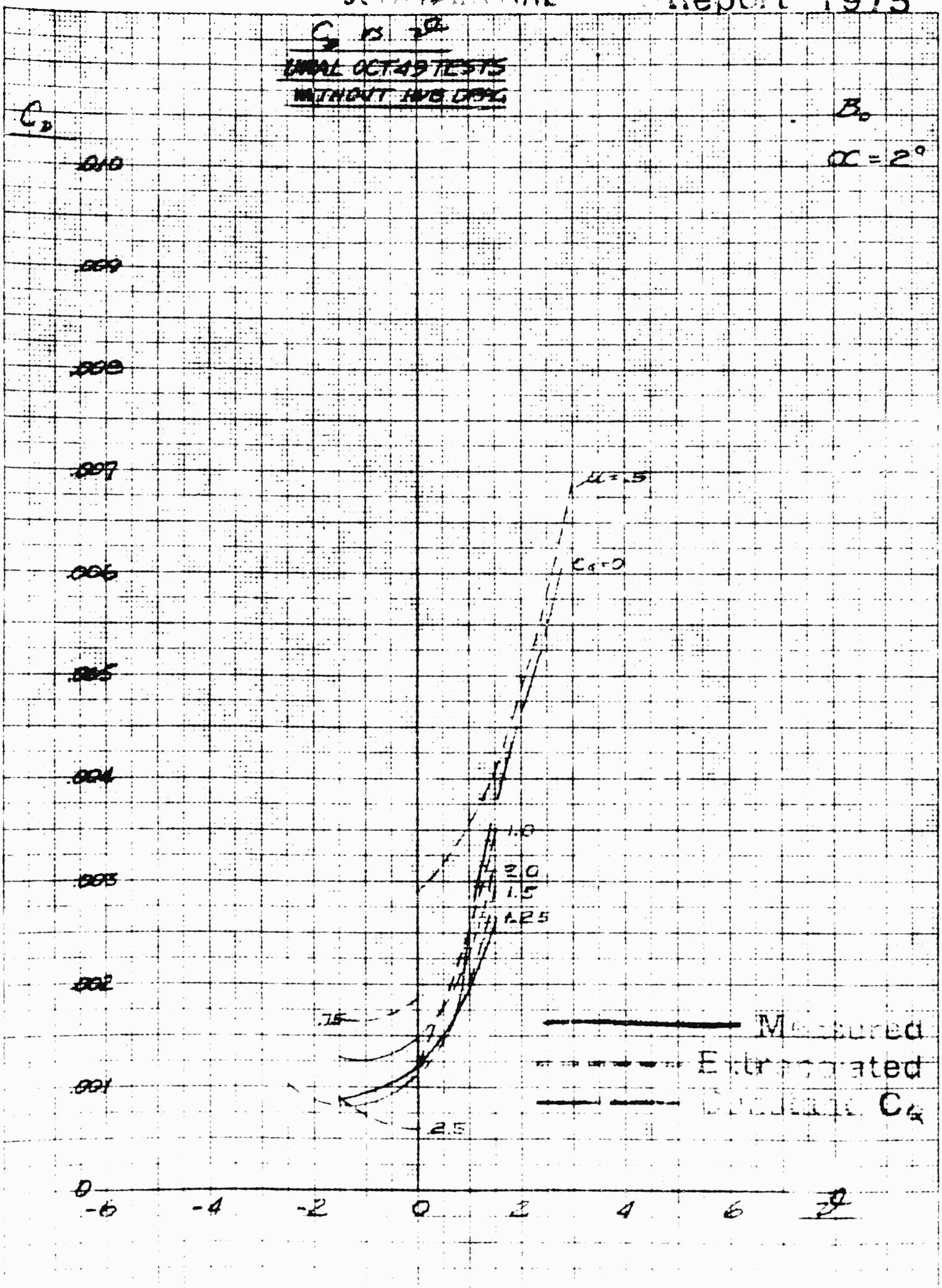
CONFIDENTIAL



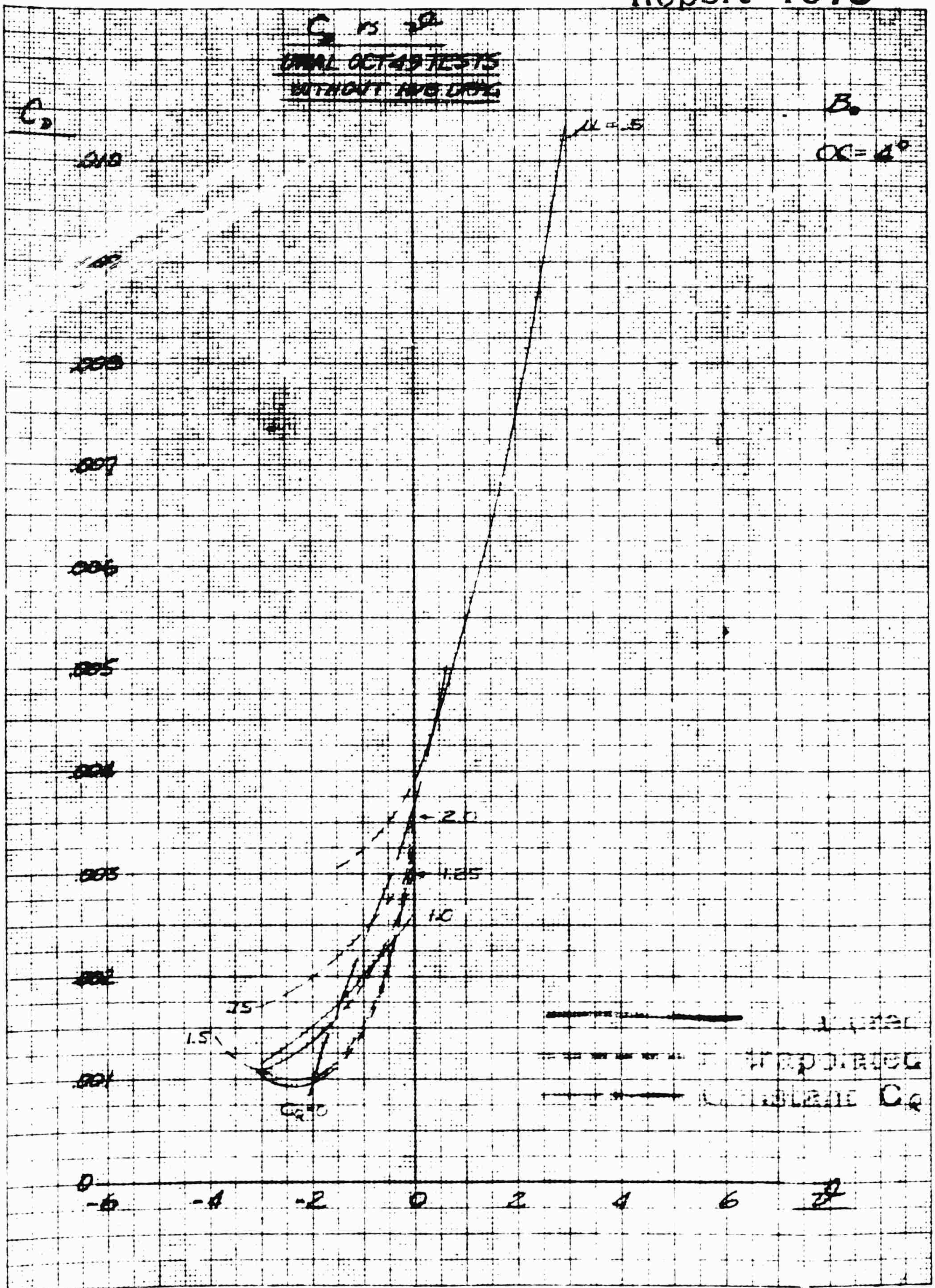

C_T vs λ
$10^2 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\alpha = 10°$
Measured
Extrapolated
Constant C_Q
40
36
32
28
24
20
16
12
8
4
0
-6
-4
-2
0
2
4
6
λ
μ=.5



C_D vs. 7^{α}
UWAL OCT 49 TESTS
WITHOUT SWB DRAG
C_D
B_c
$\alpha = 0°$
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
-6
-4
-2
0
2
4
6
$C_R = 0$
1.25
1.5
2.0
Measured
Extrapolated



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

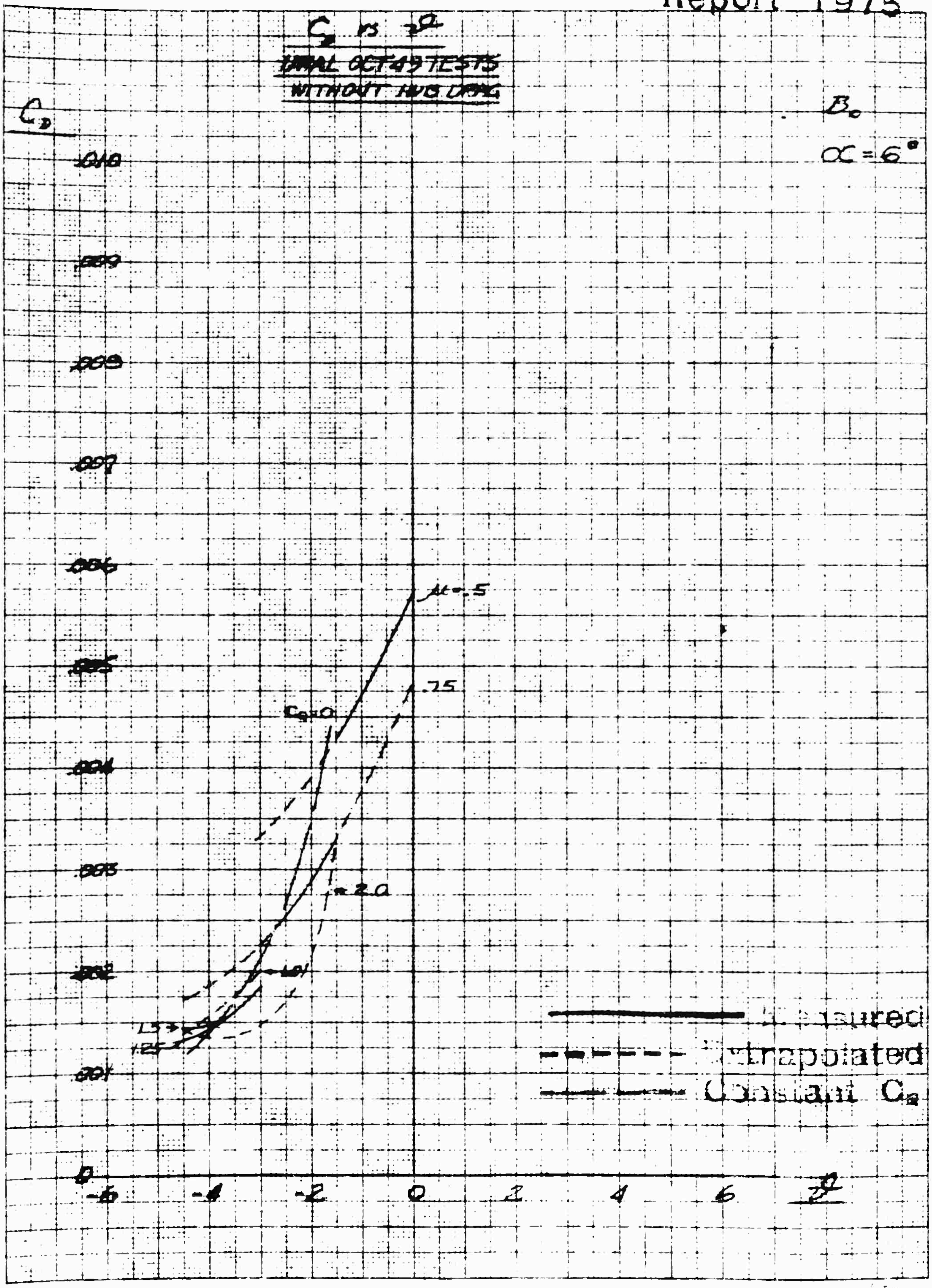


No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

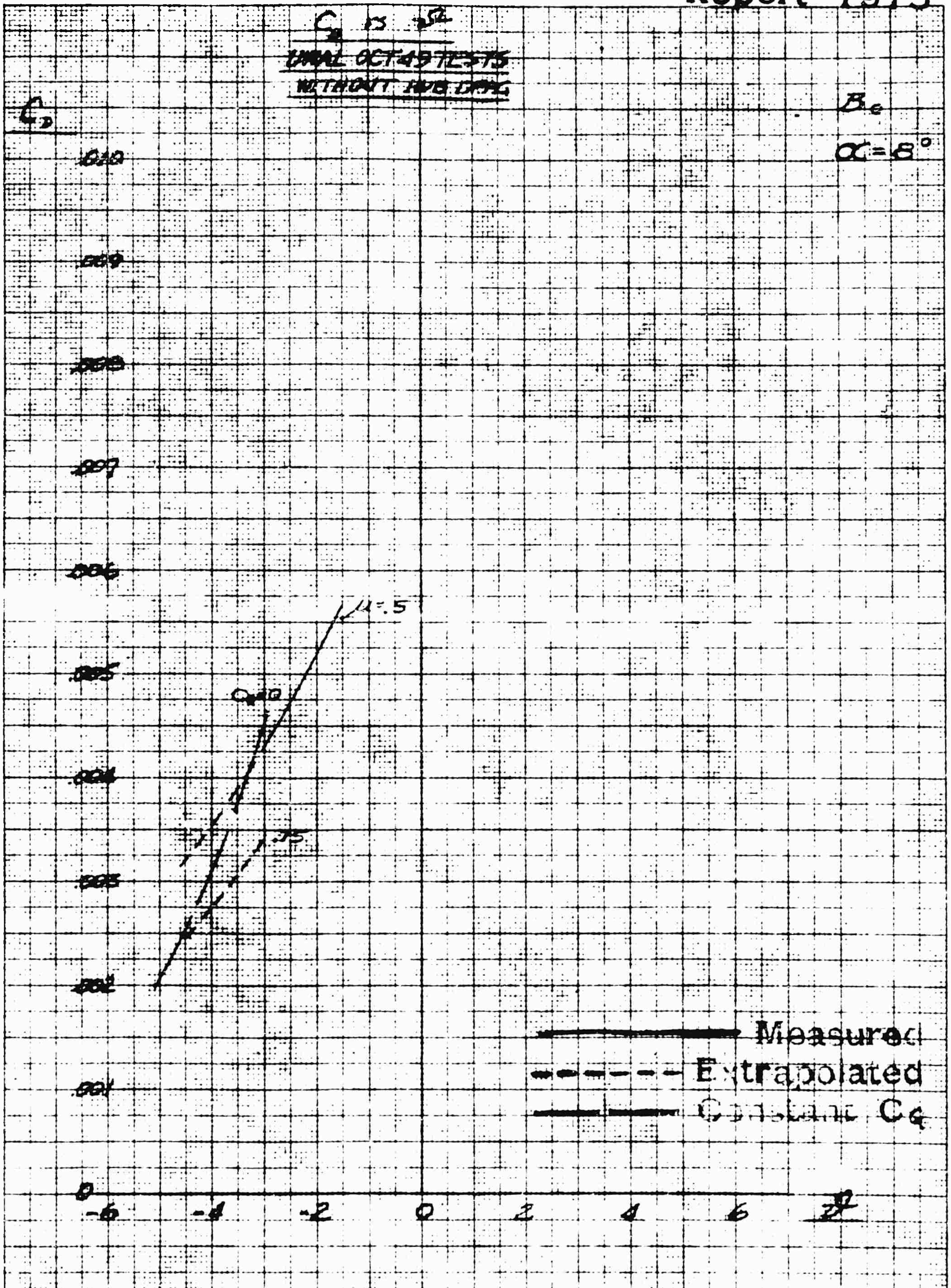
CONFIDENTIAL

254

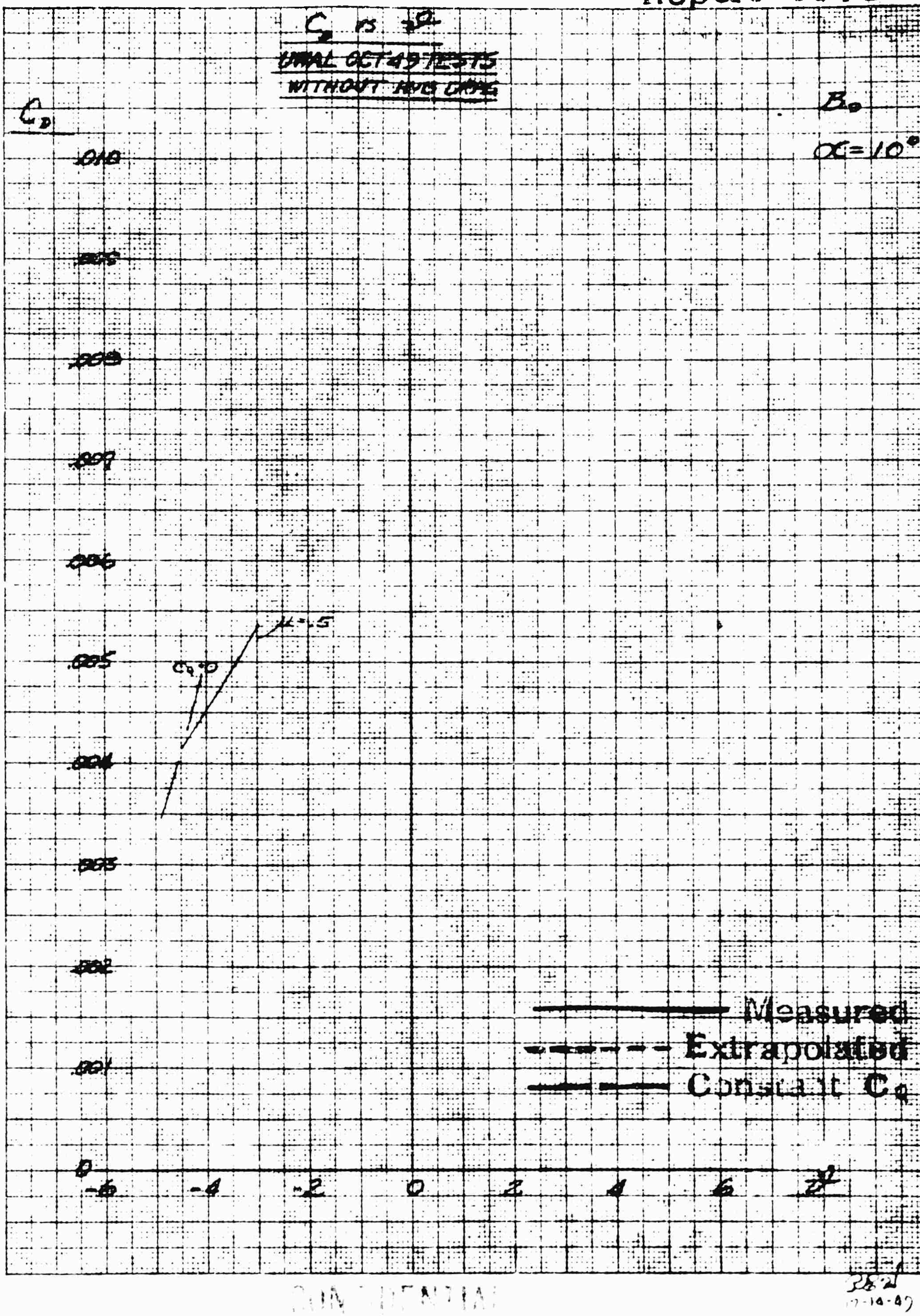
Report 1975



KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

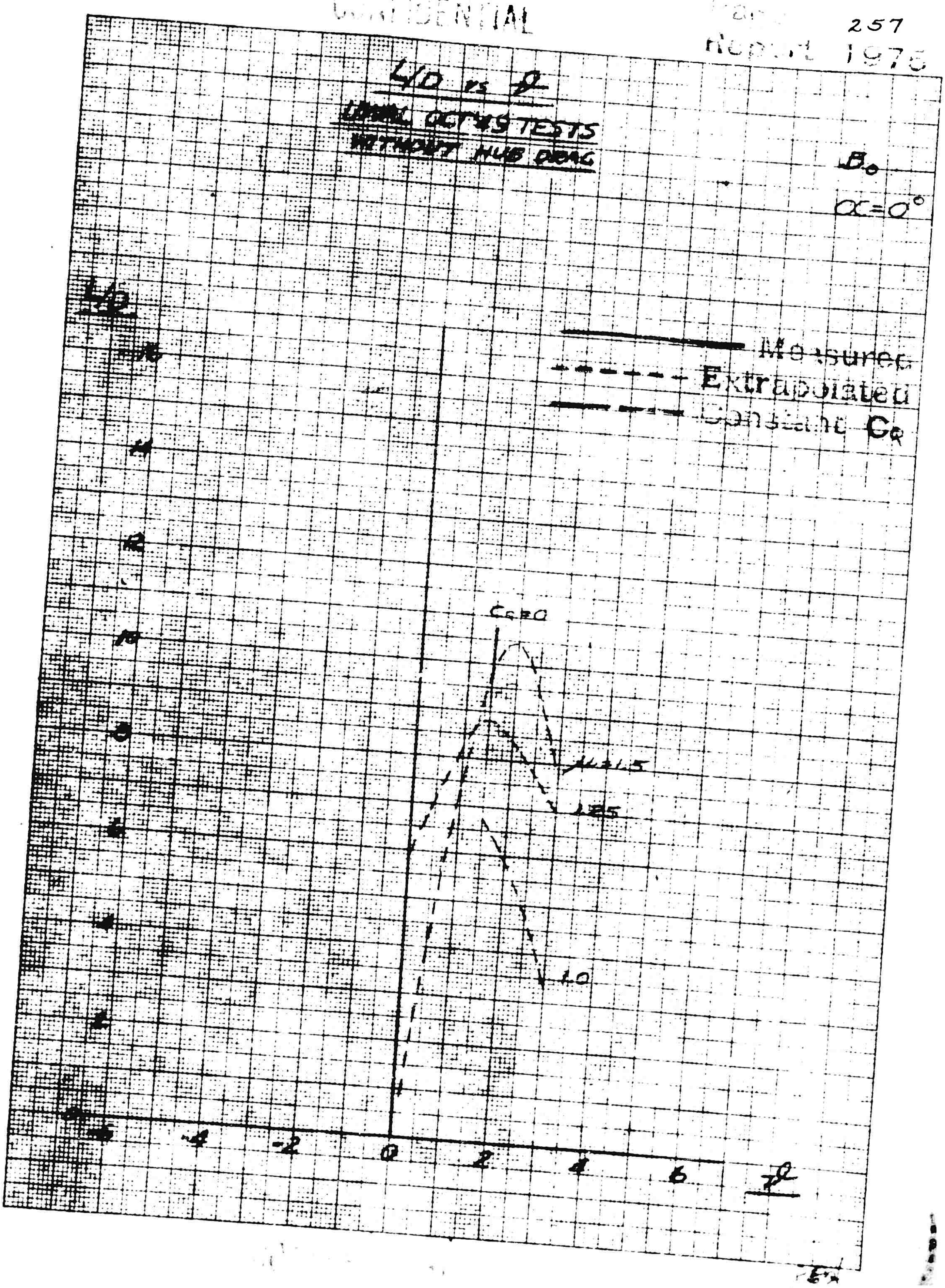


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



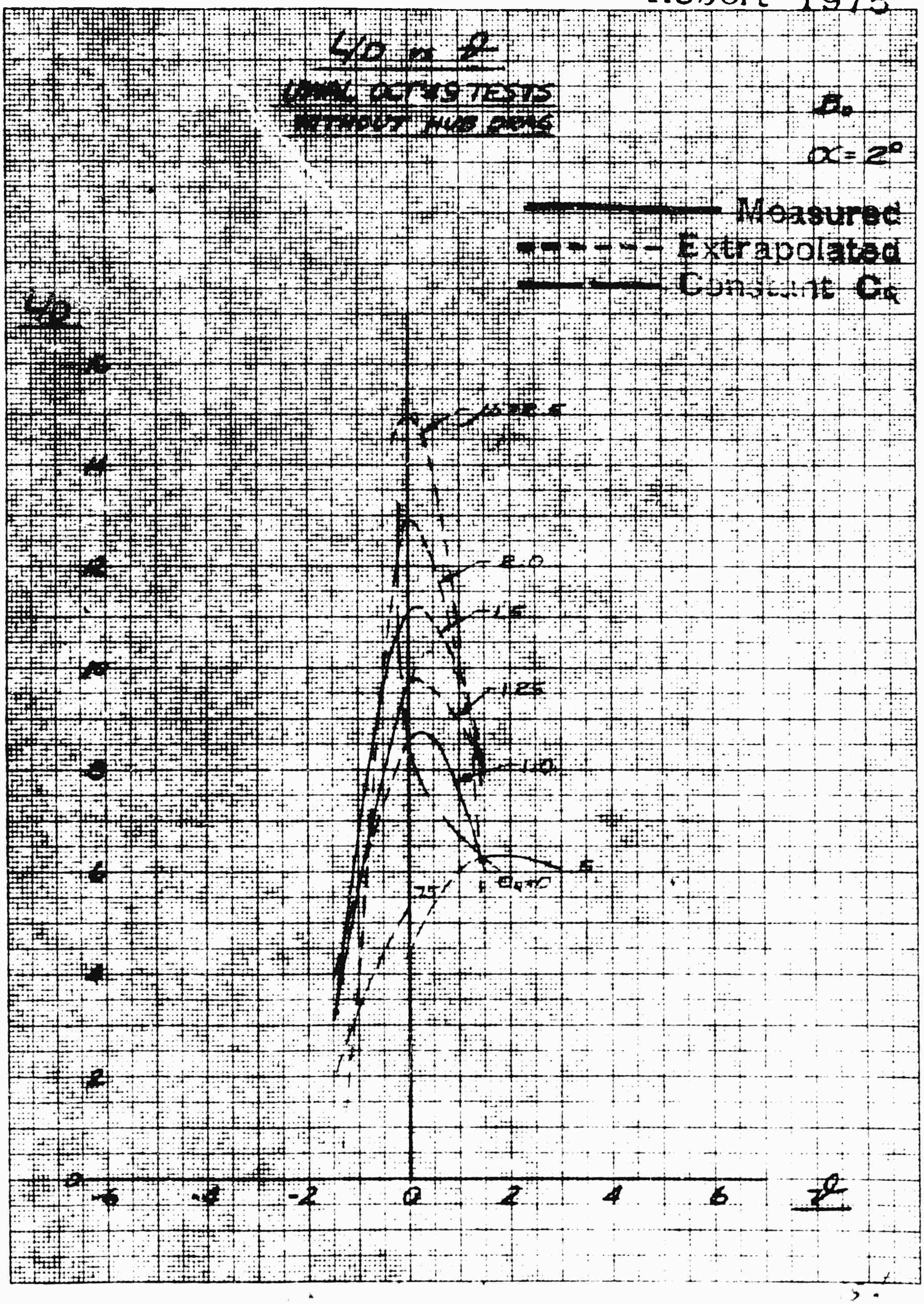
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

12-14-49

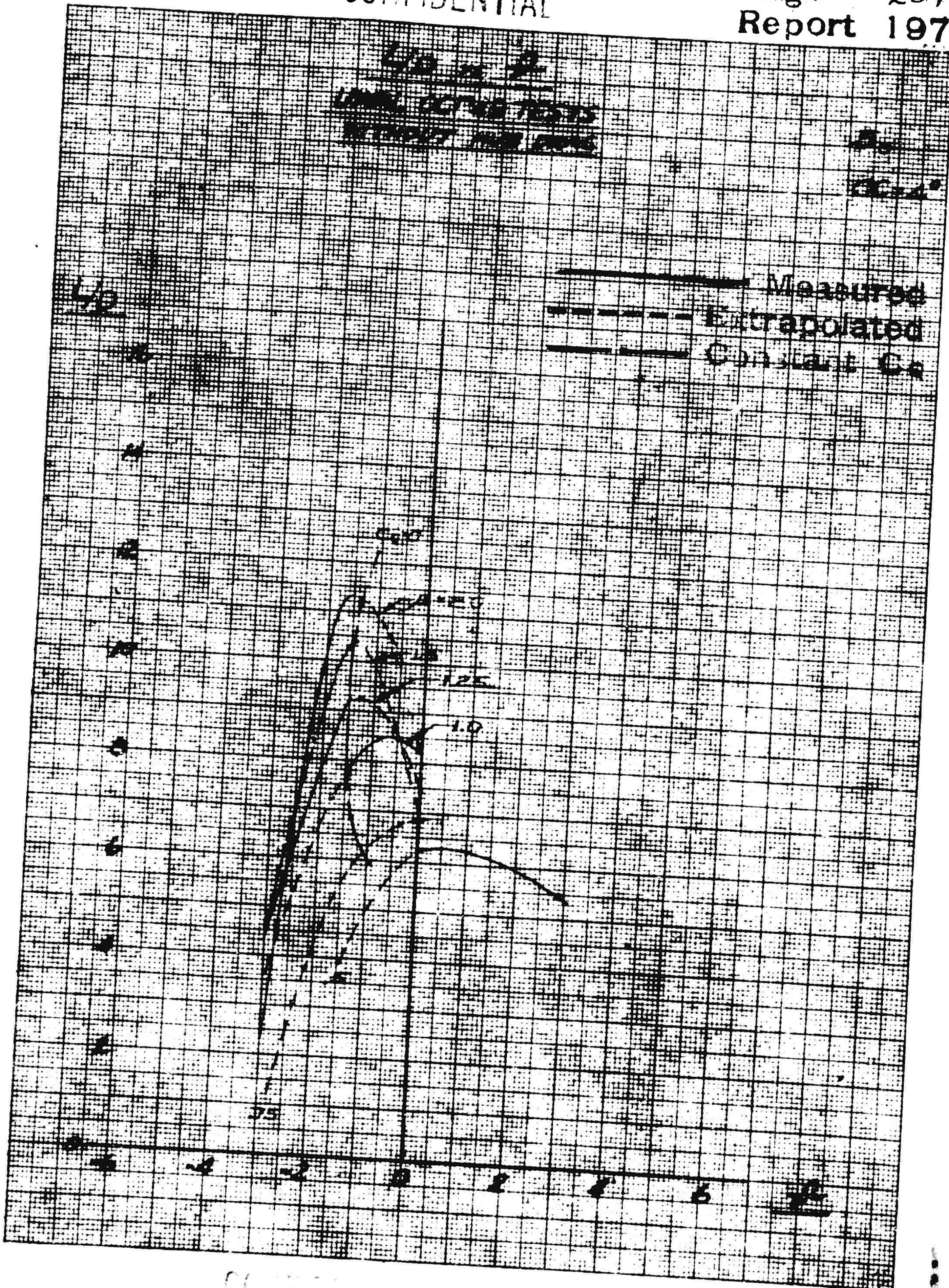


KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

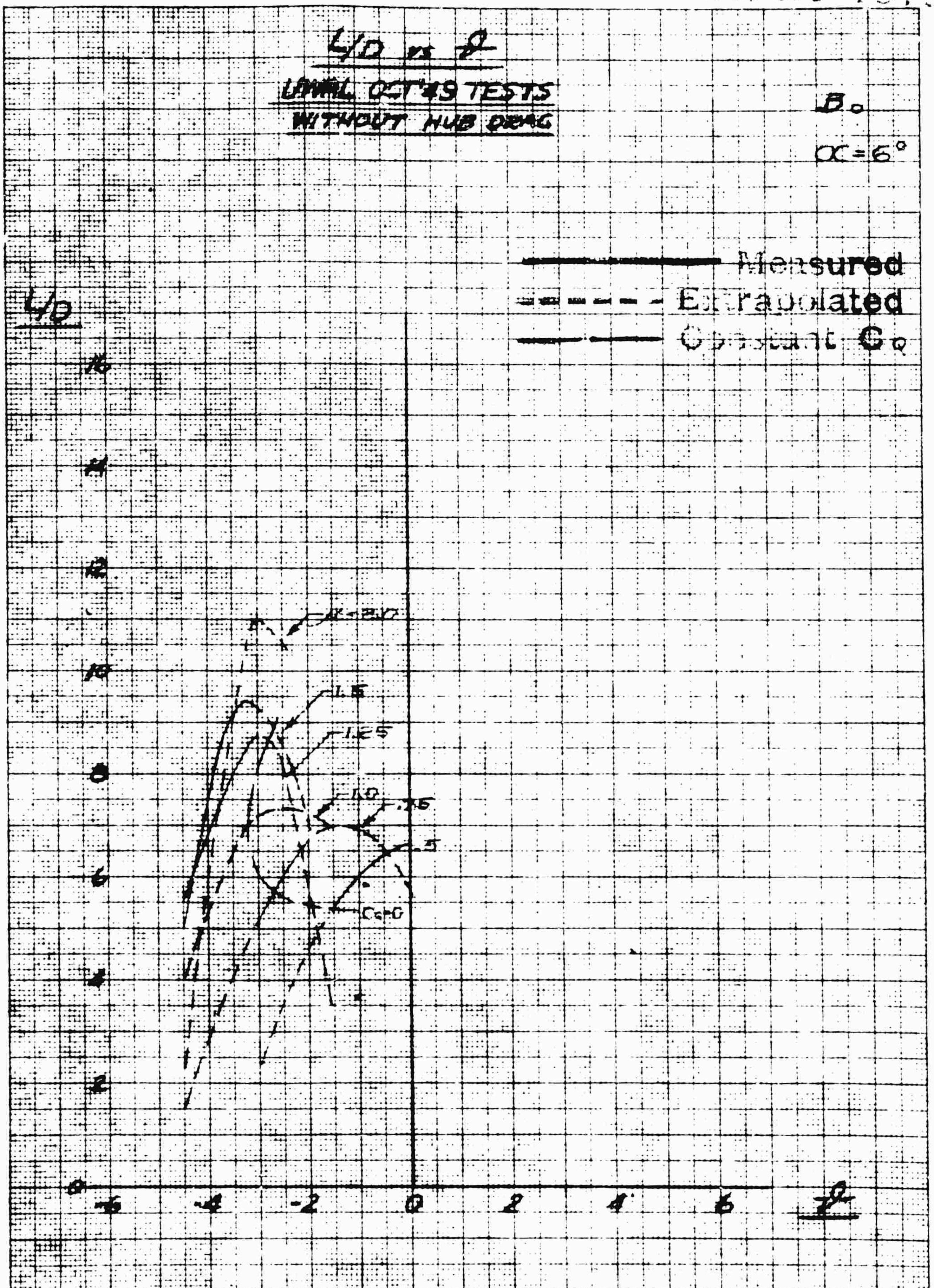


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

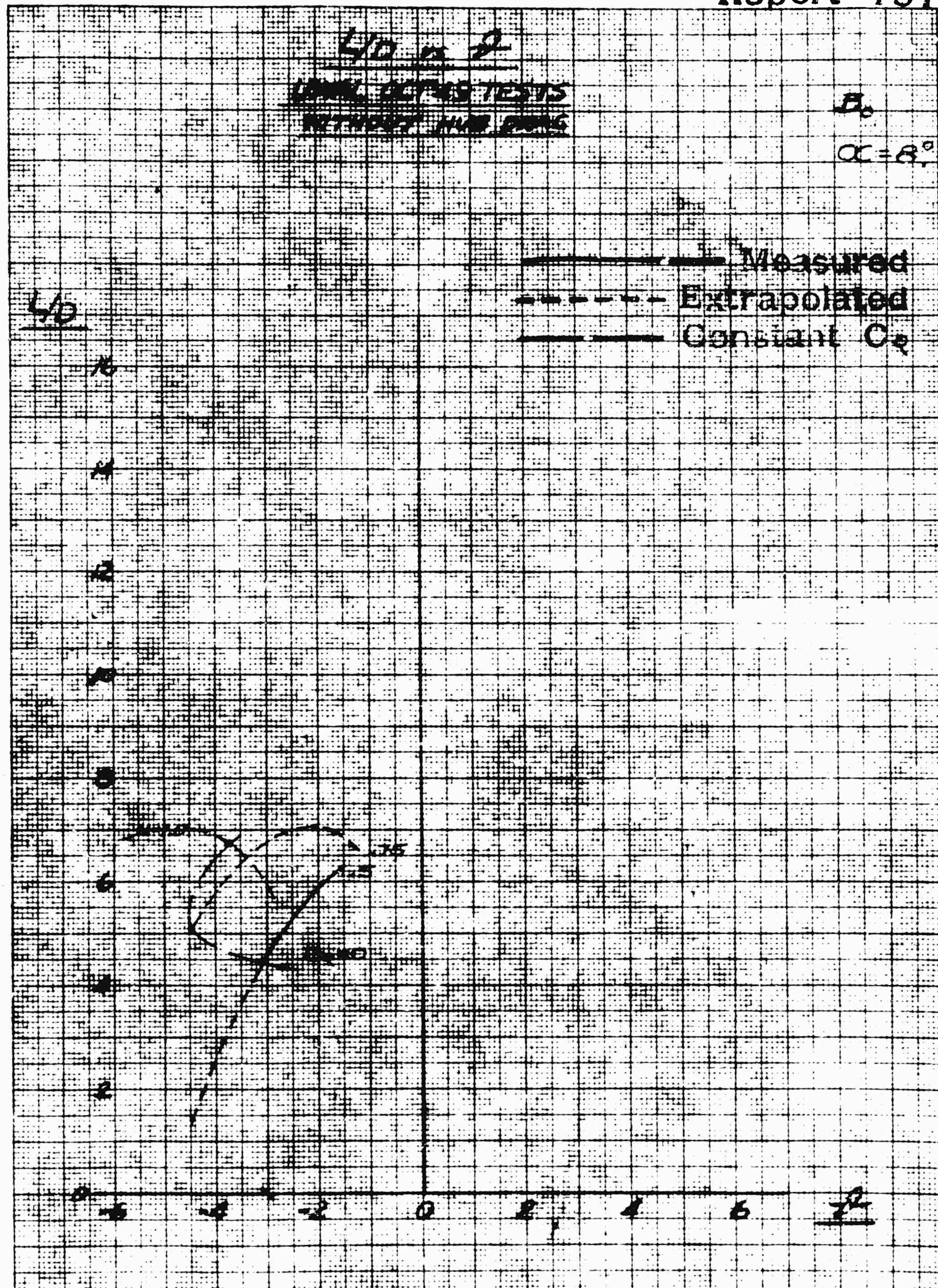


KEUFFEL & ESSER CO.
No. 358-14. Millimeters, 5 mm lines accented, cm lines heavy.

12-13-49

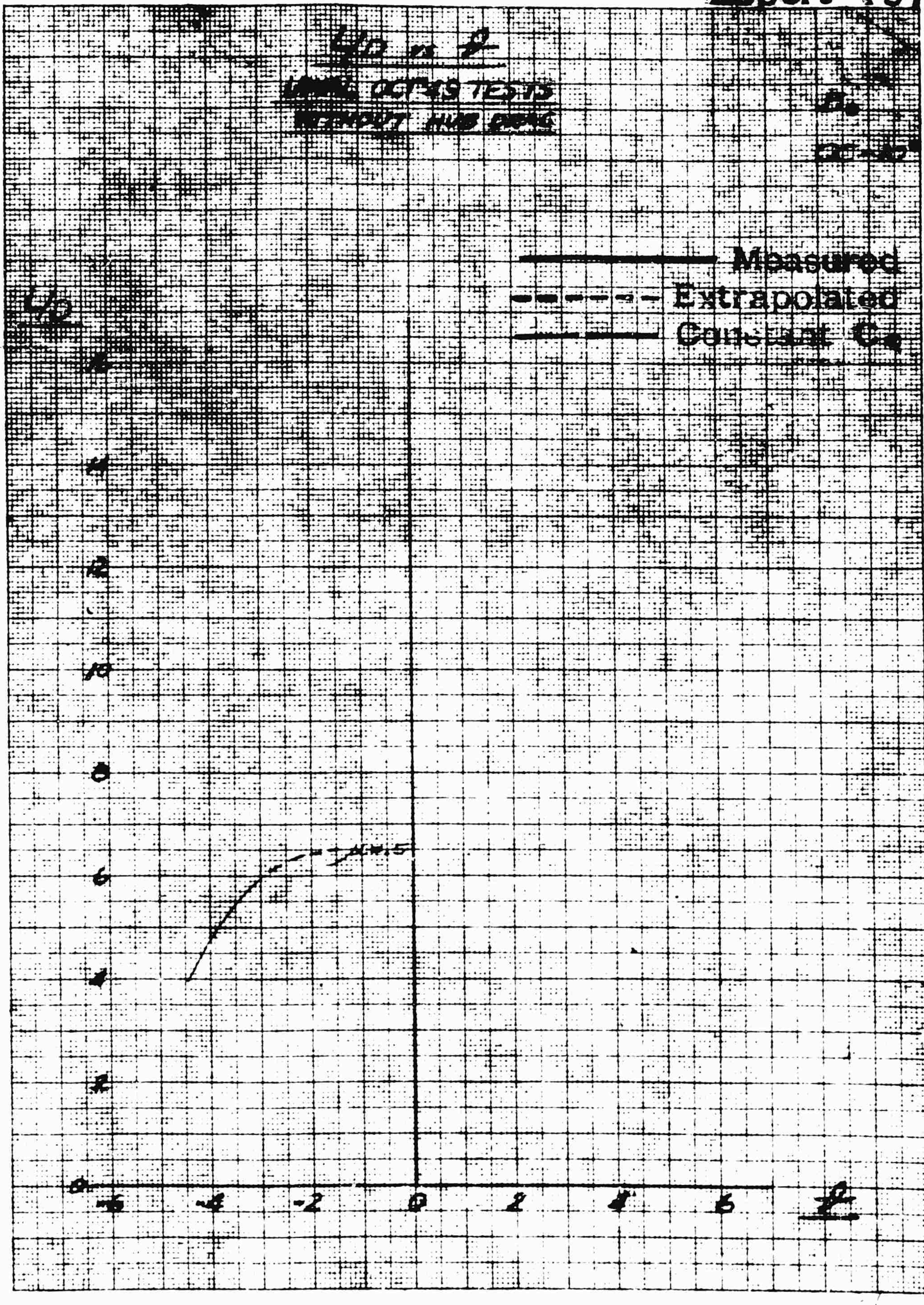


No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

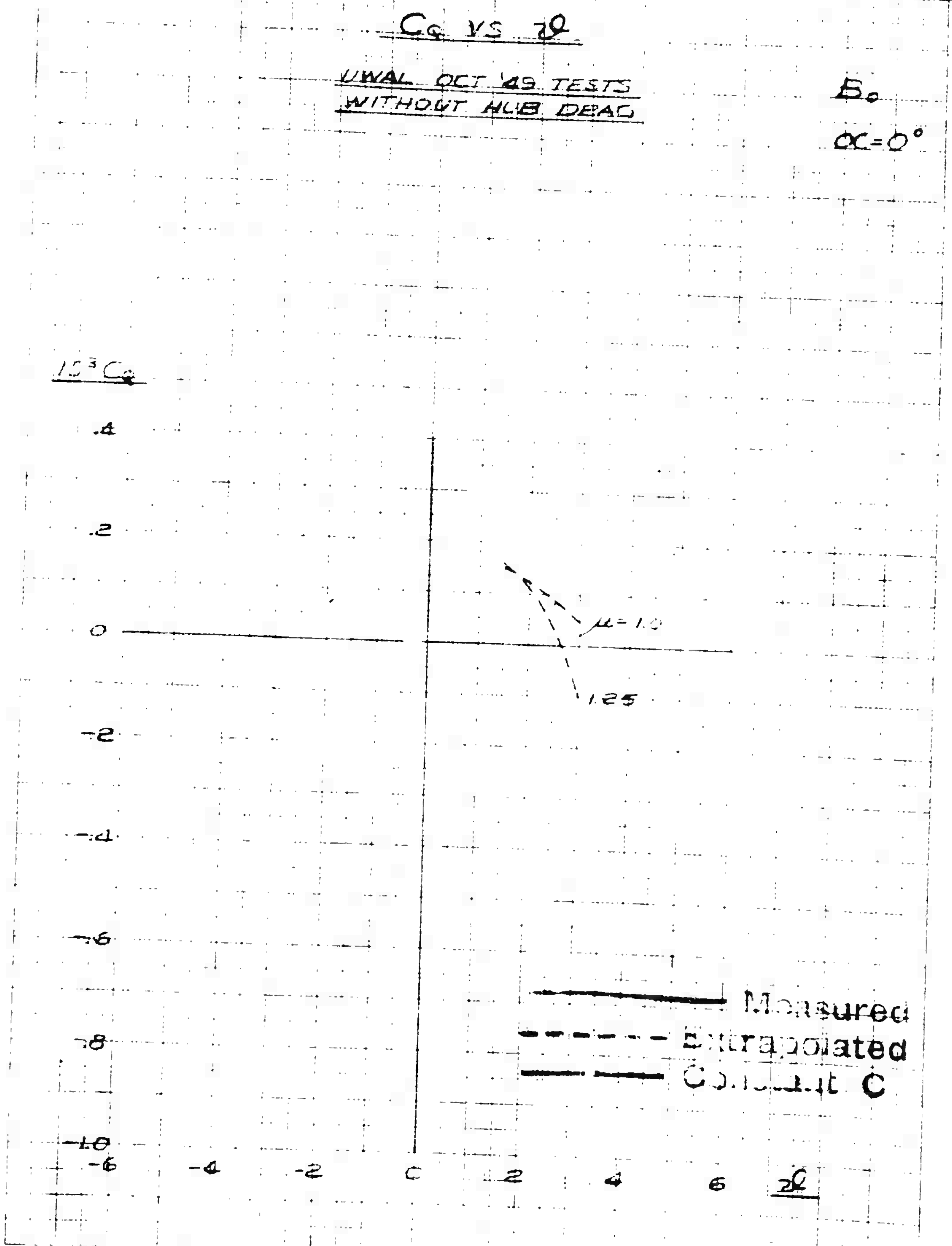


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

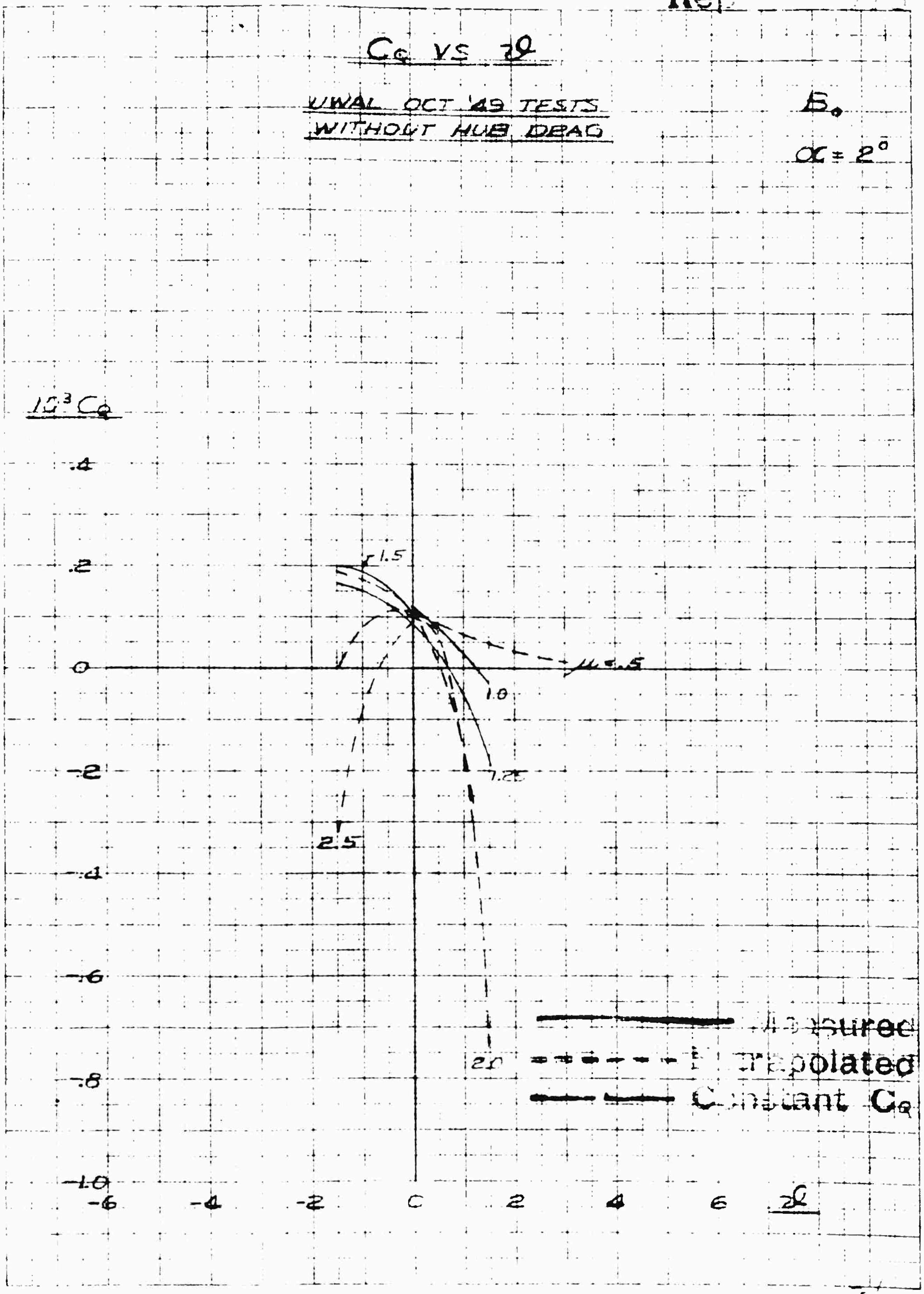
CONFIDENTIAL

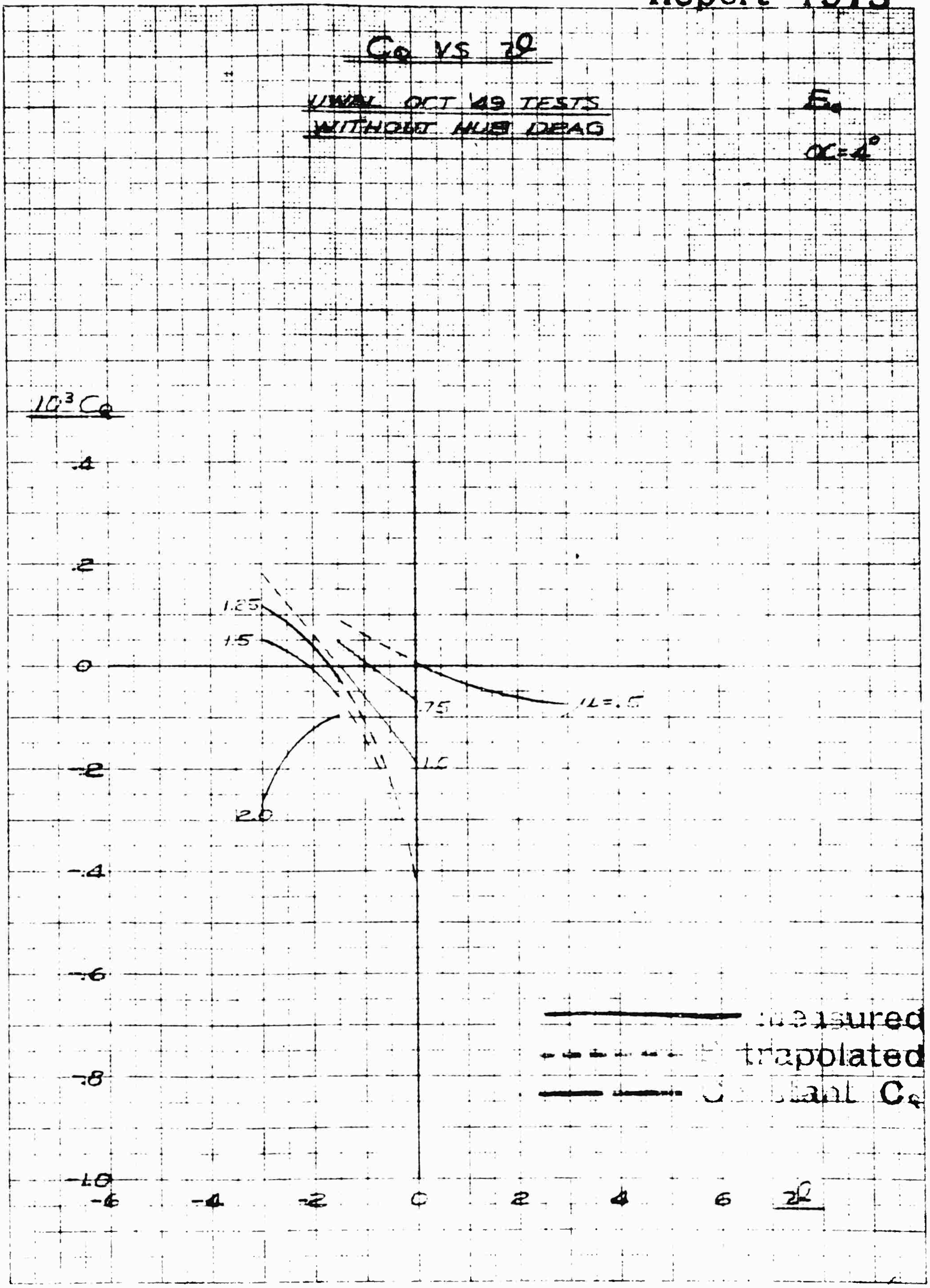


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented cm lines heavy.

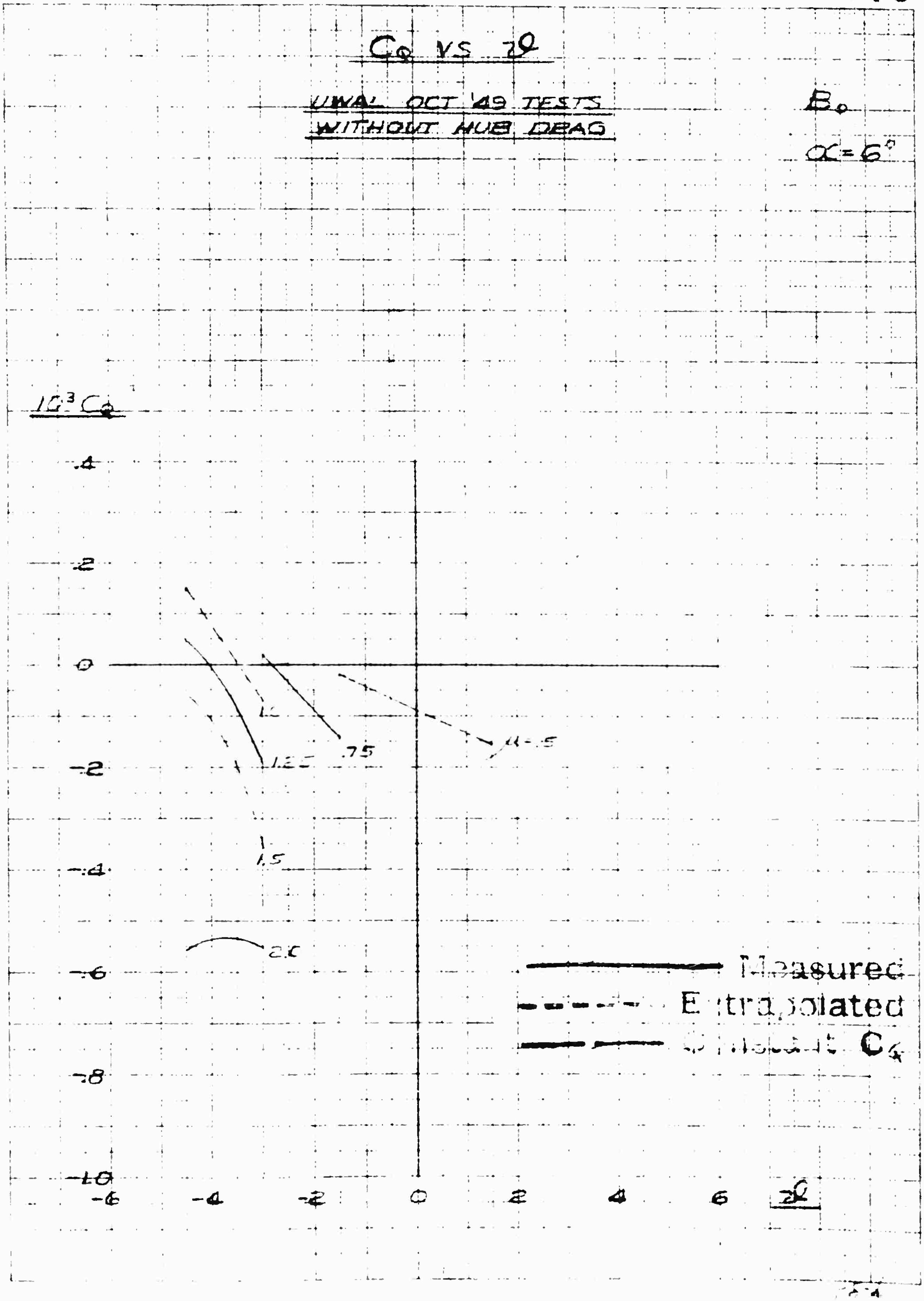

C_Q VS θ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_o
$\alpha = 0°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
θ
$\mu = 1.0$
1.25
Measured
Extrapolated
Constant C

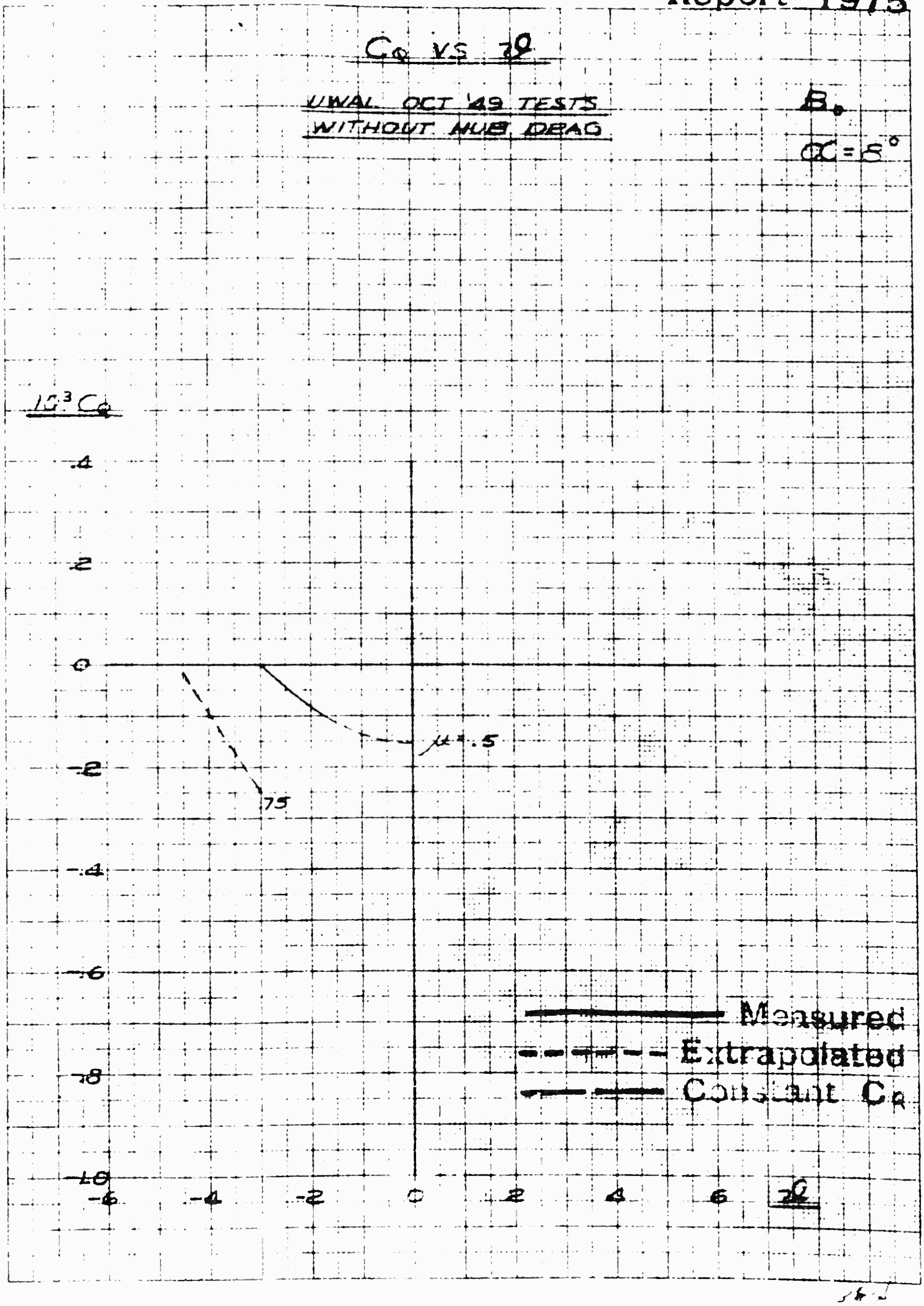
Rep


CQ VS λ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B₀
α = 2°
10³ CQ
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
λ
1.5
μ = .5
1.0
1.25
2.5
2.0
Measured
Extrapolated
Constant CQ

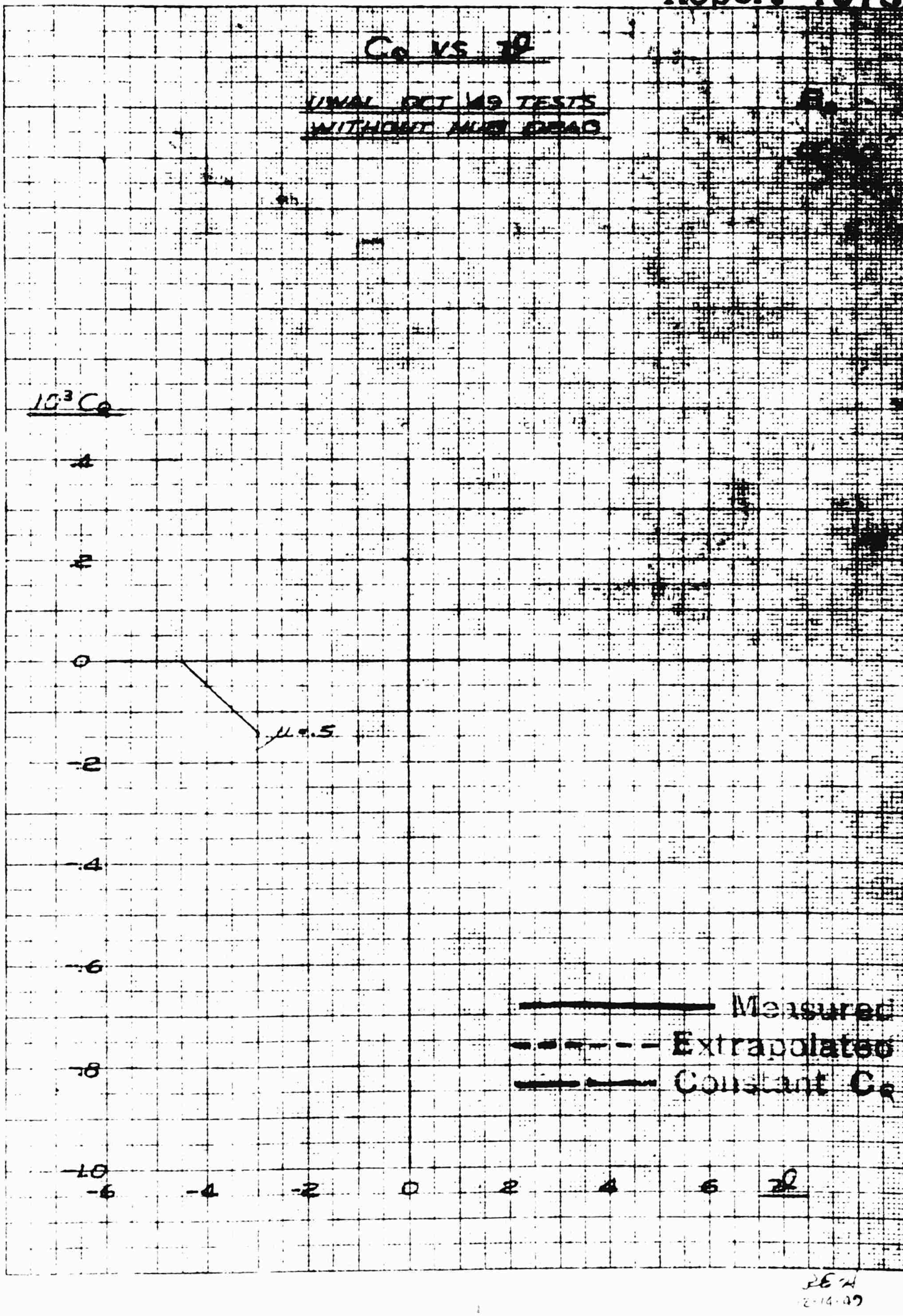


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

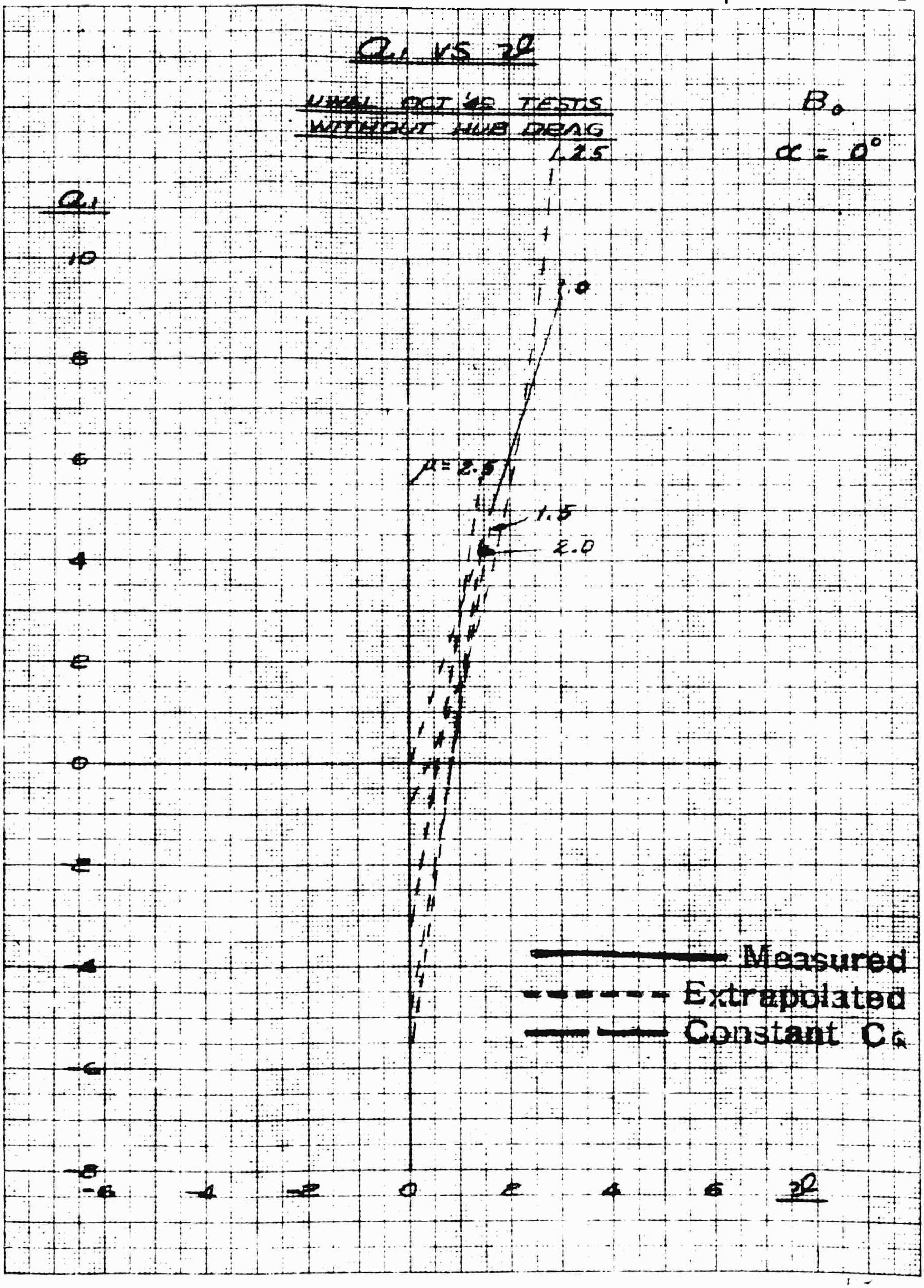

C_Q VS $\bar{\mu}$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_0
$\alpha = 6°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-6
-4
-2
0
2
4
6
1.0
1.25
.75
μ = .5
1.5
2.0
Measured
Extrapolated
Constant C_4


C_Q VS λ
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
$\alpha = 8°$
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-.6
-.4
-.2
0
.2
.4
.6
λ
$\mu = .5$
.75
Measured
Extrapolated
Constant C_Q

CONFIDENTIAL



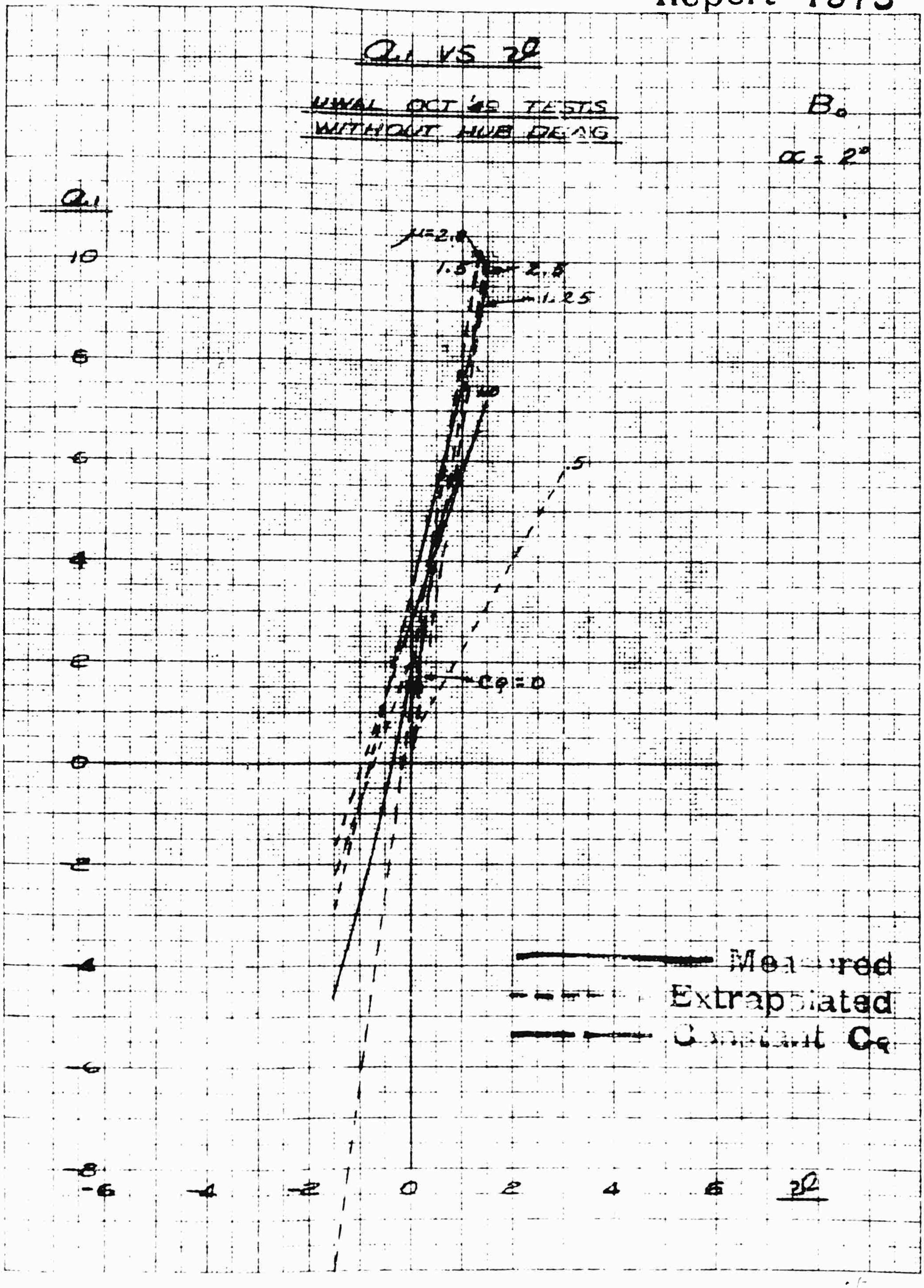
KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy

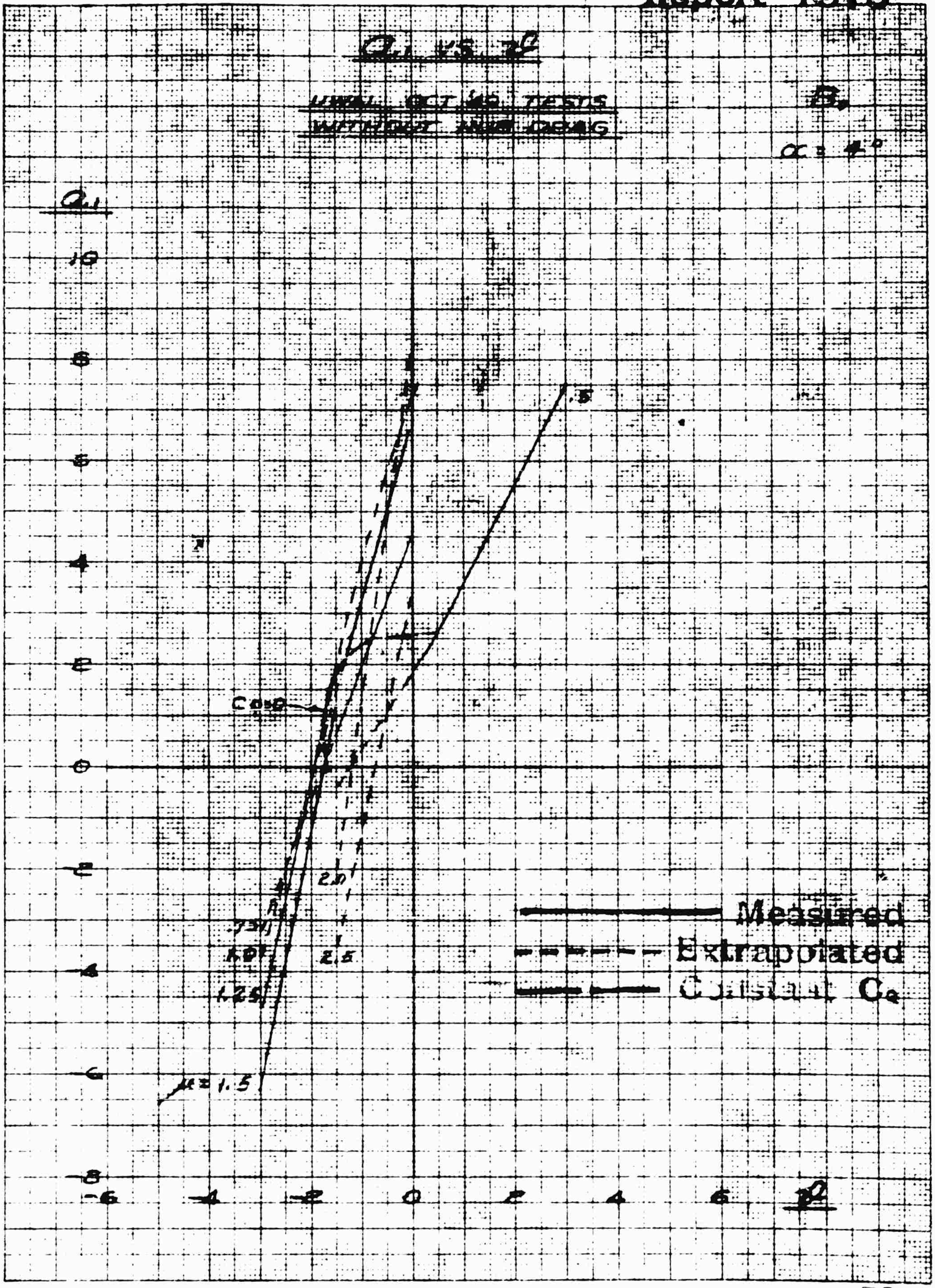


No 359 14. Millimeters, 5 mm lines accented, cm lines heavy

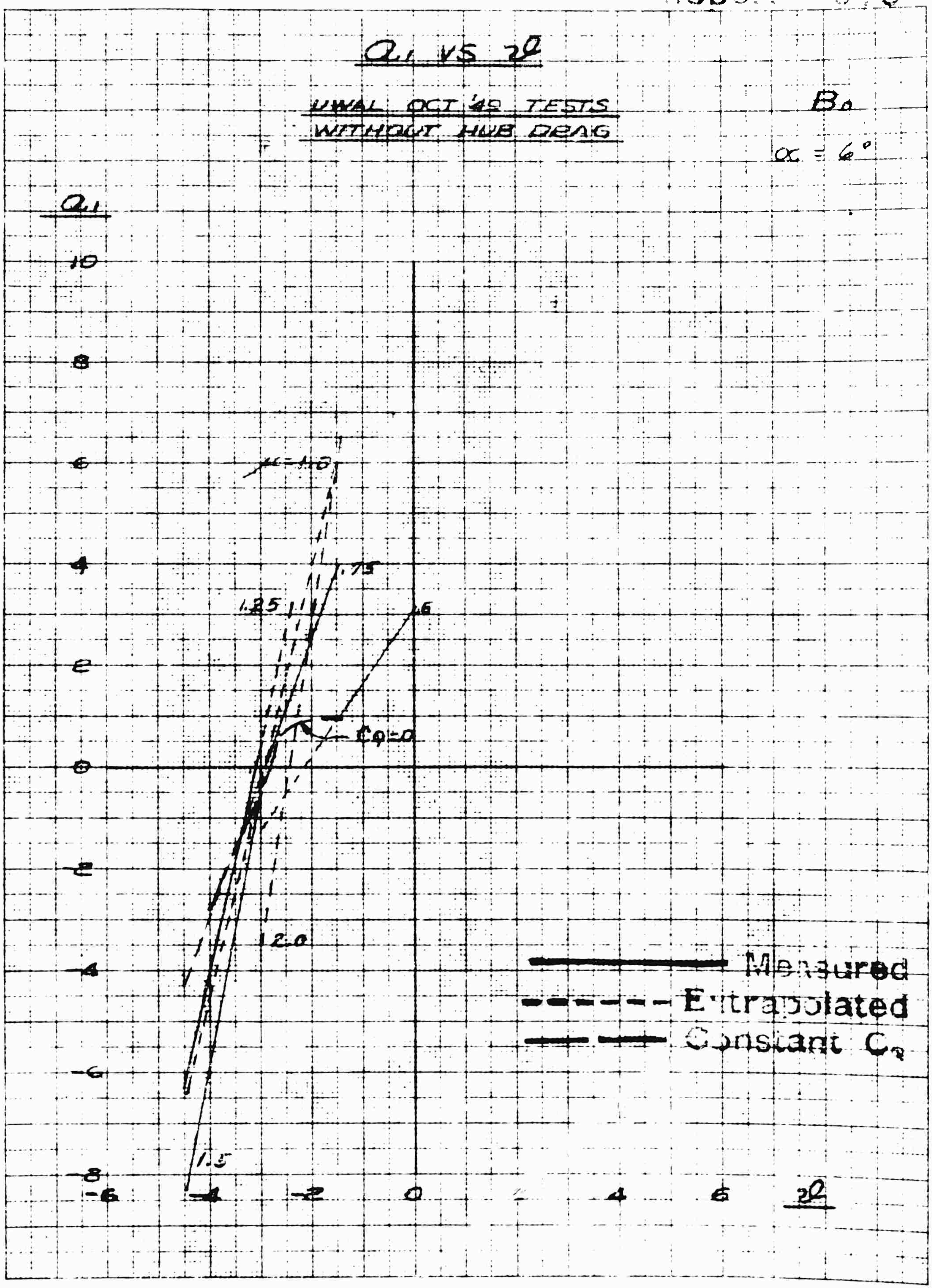
270

Report 1975

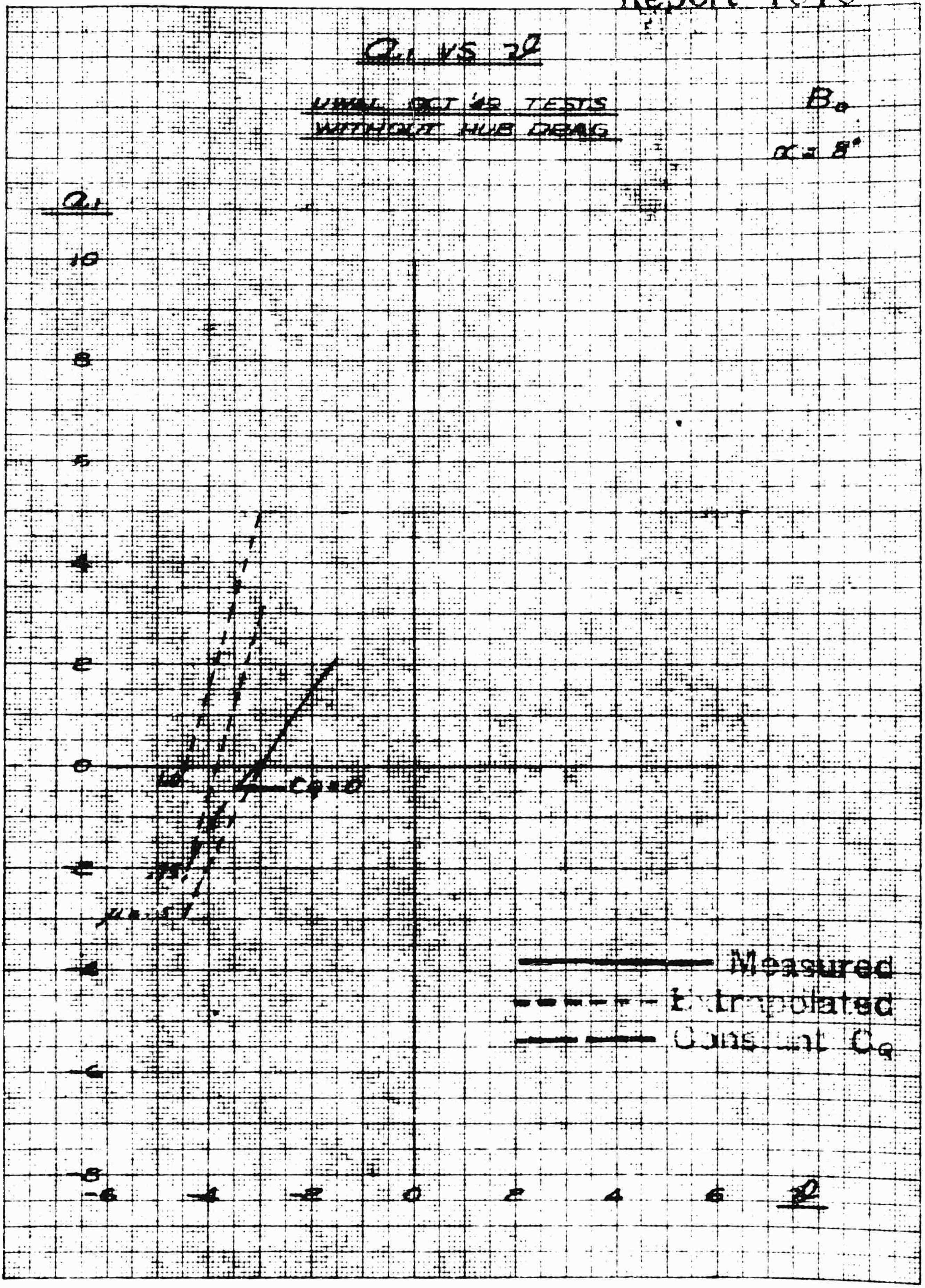



C_l VS. β
UWAL OCT 46 TESTS
WITHOUT WING DRAG
B_x
$\alpha = 4°$
C_l
10
8
6
4
2
0
-2
-4
-6
-8
-6
-4
-2
0
2
4
6
β
$C_D = 0$
2.0
2.5
.75
1.0
1.25
$\mu = 1.5$
.5
Measured
Extrapolated
Constant C_e

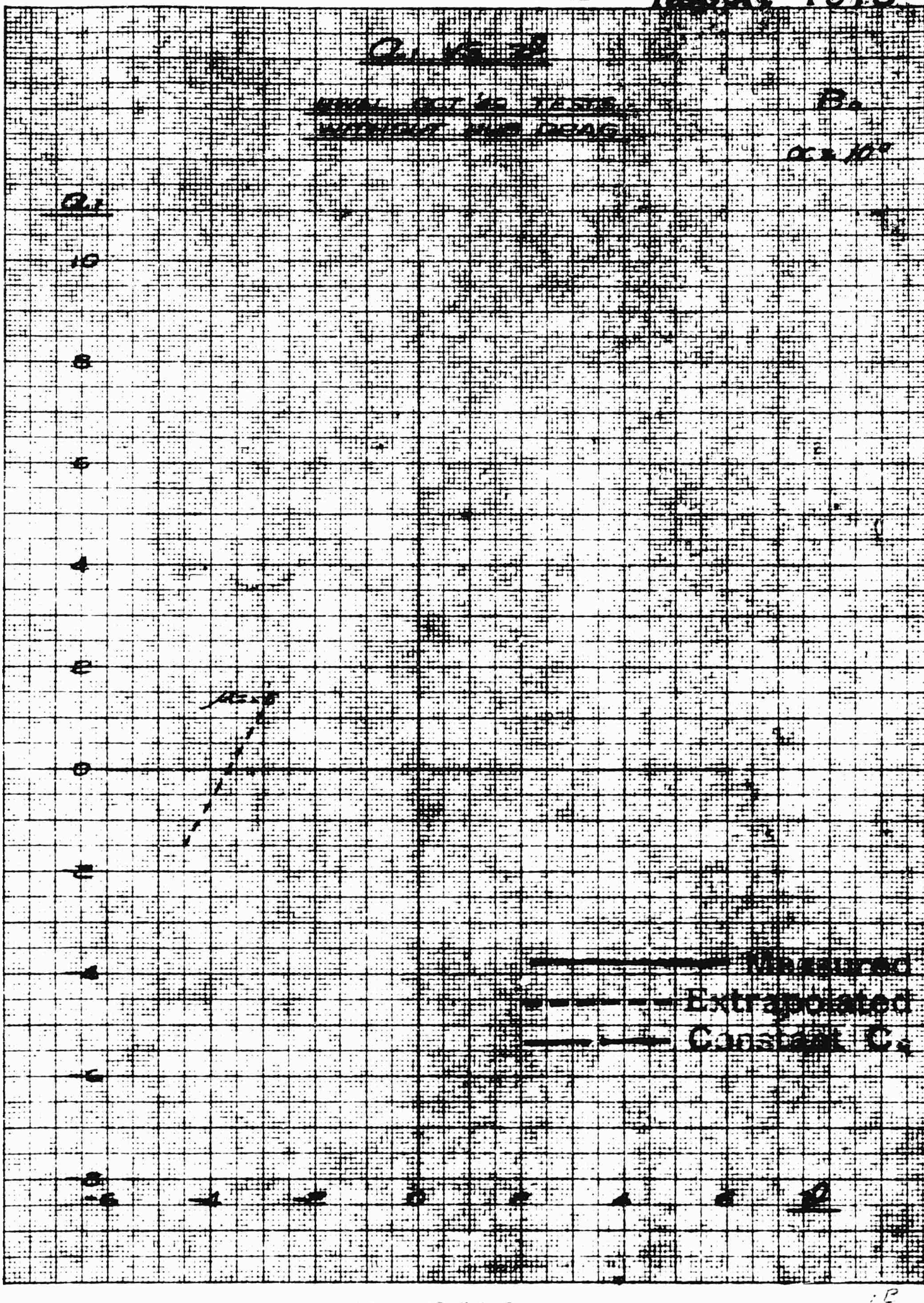
PB
12-9-46

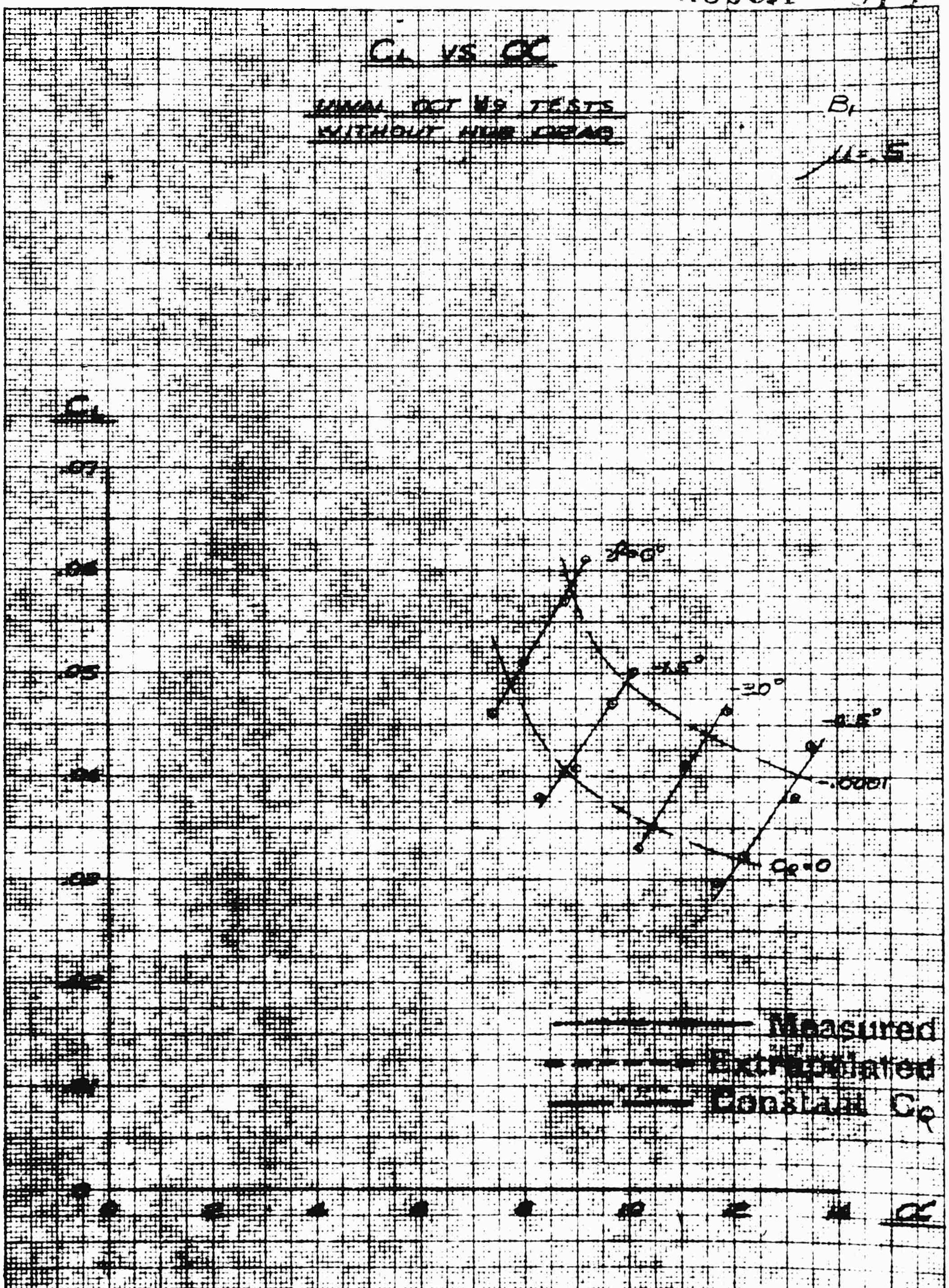


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

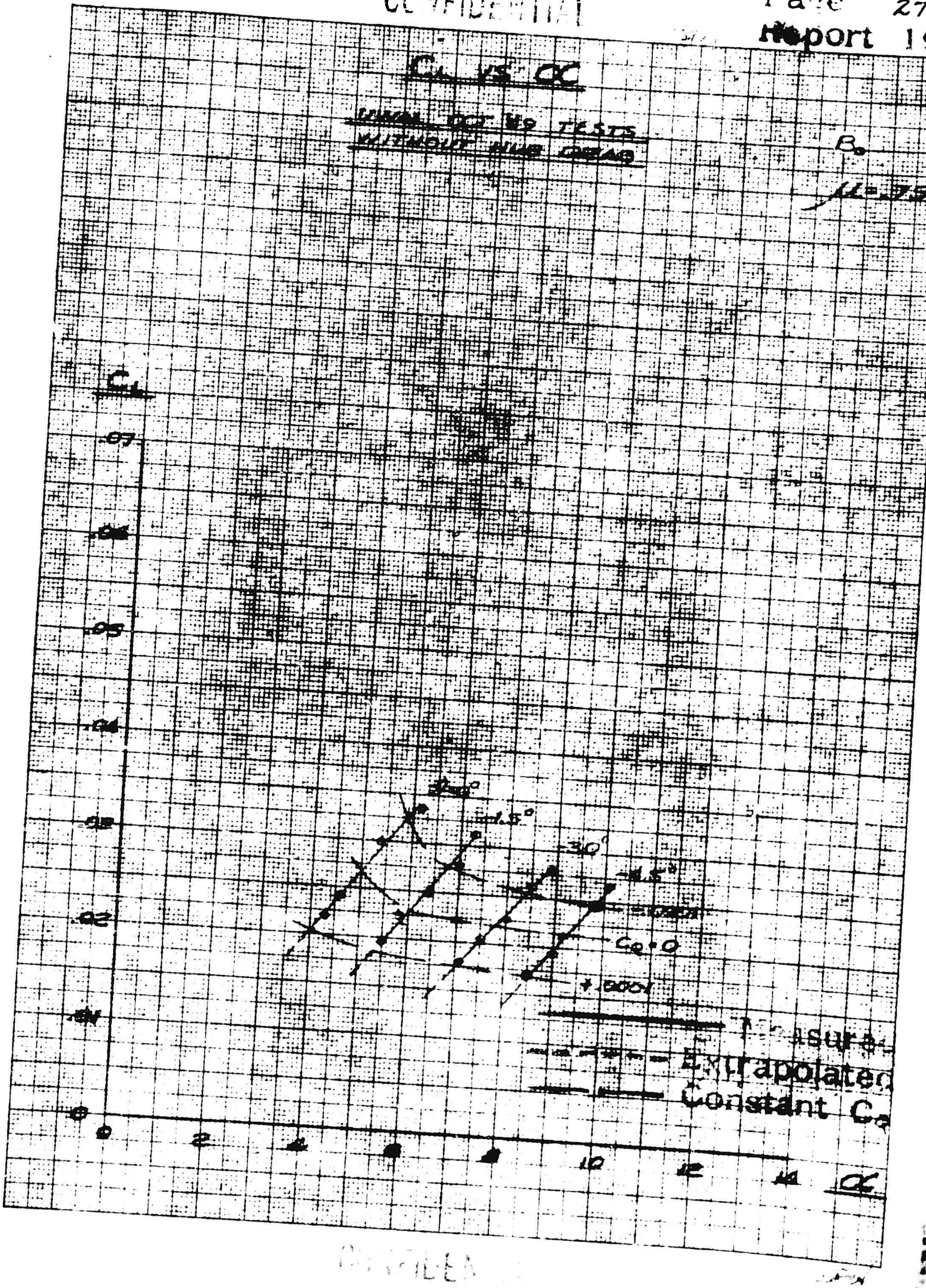


No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy
KEUFFEL & ESSER CO.

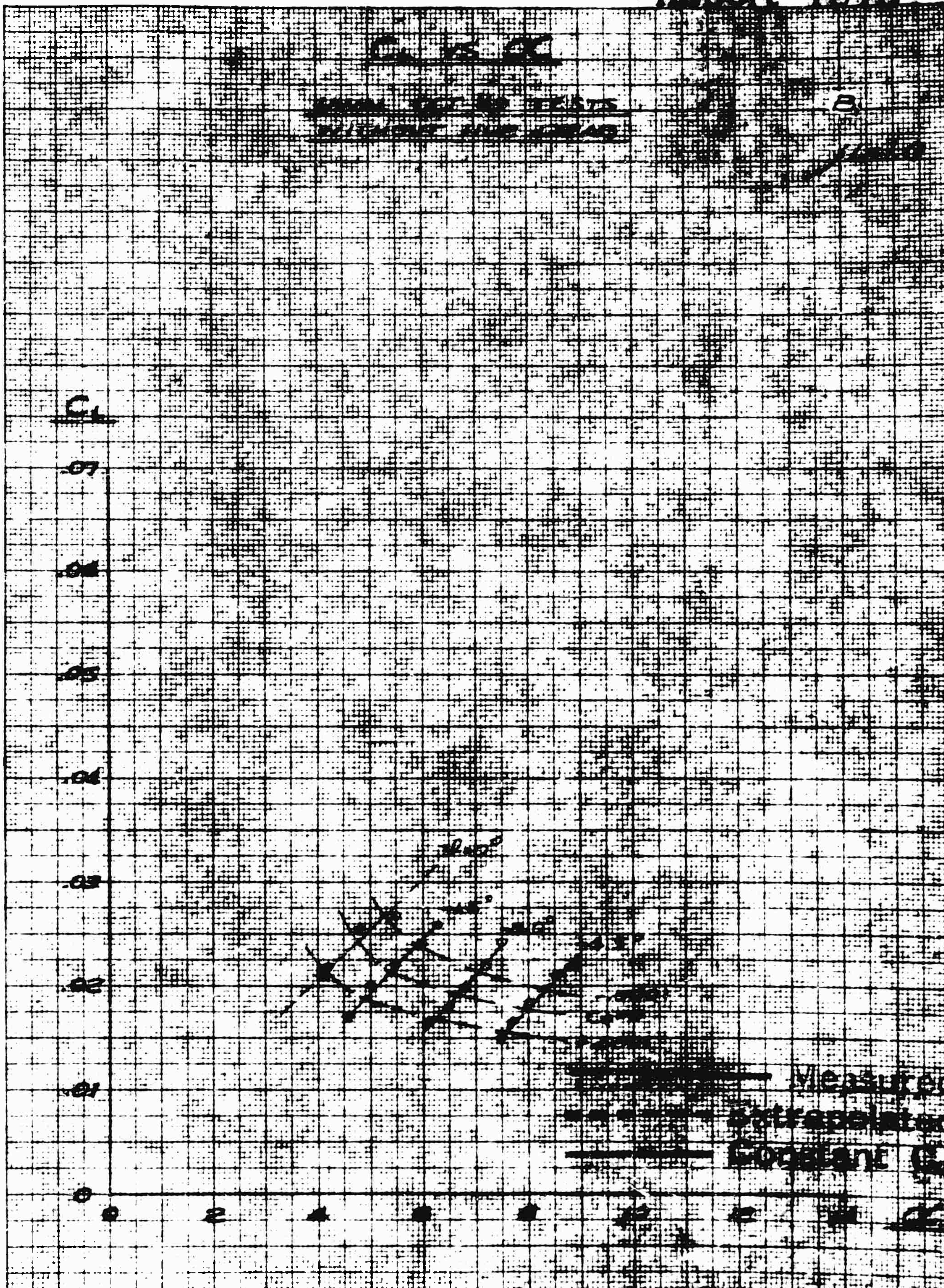

DRAG
B
10
8
6
4
2
0
-4
-6
-8
-6
-4
-2
0
2
4
6
8
Measured
Extrapolated
Constant



No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy. KEUFFEL & ESSER CO.

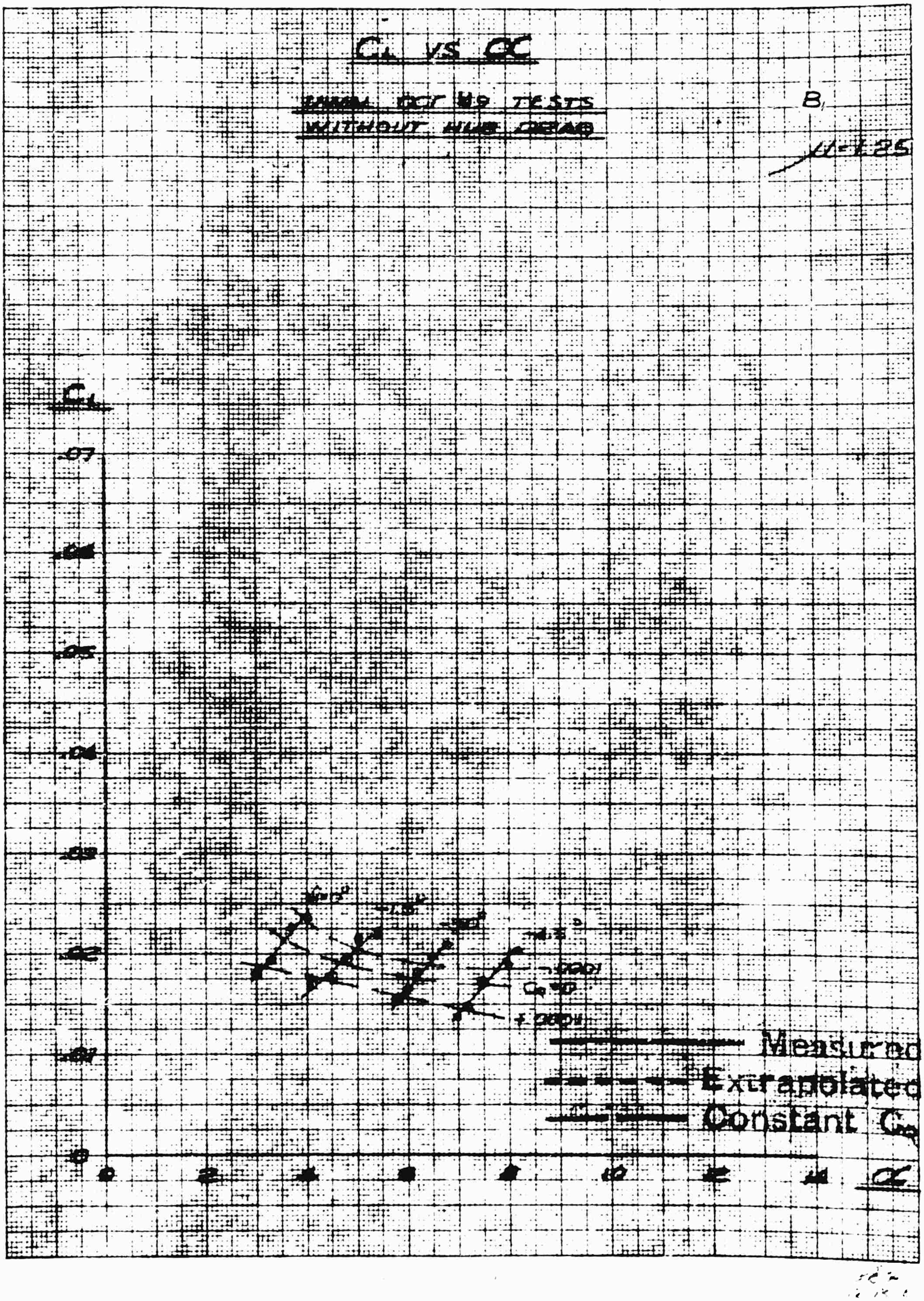


KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy.

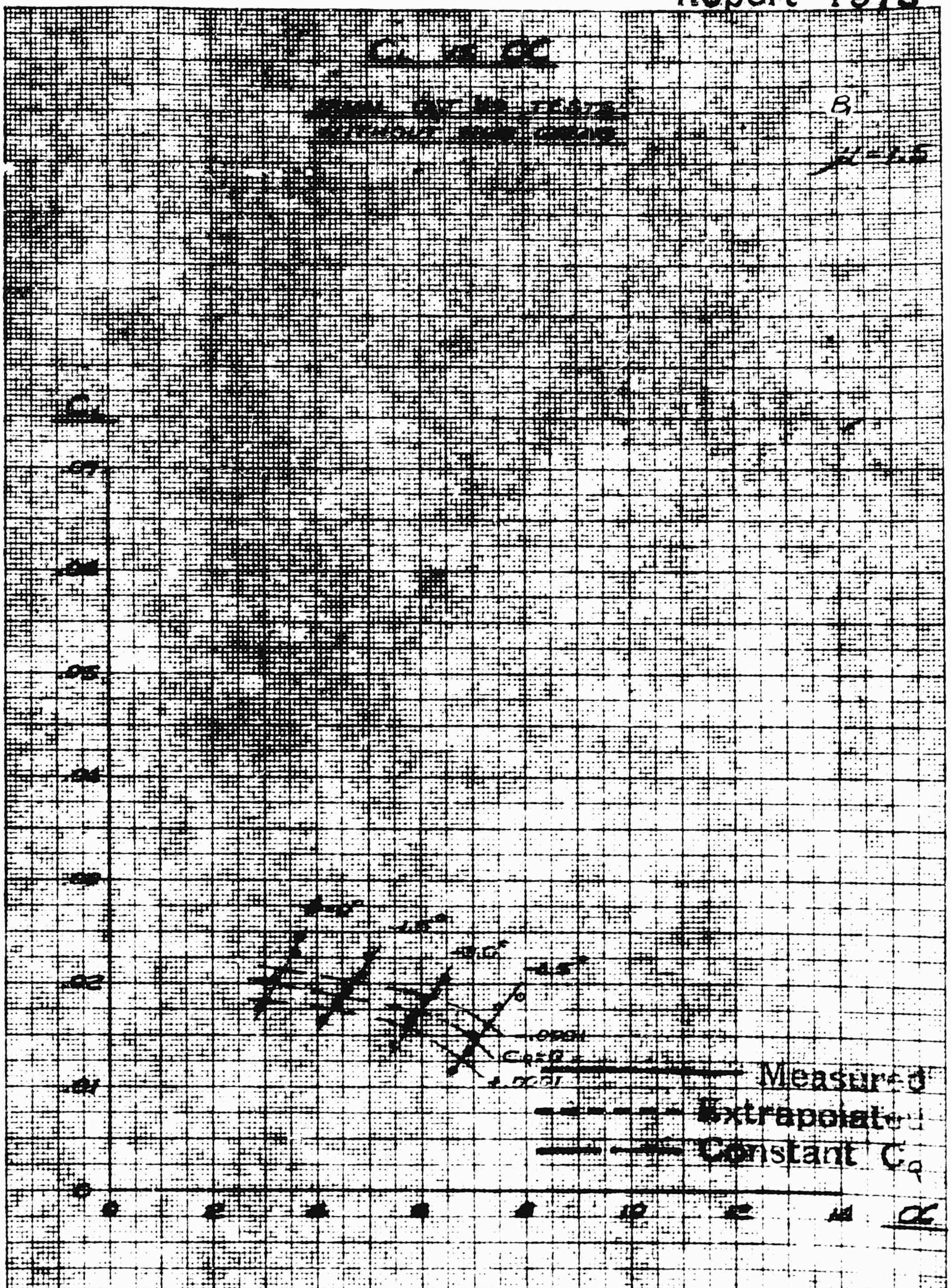


12-19-4?

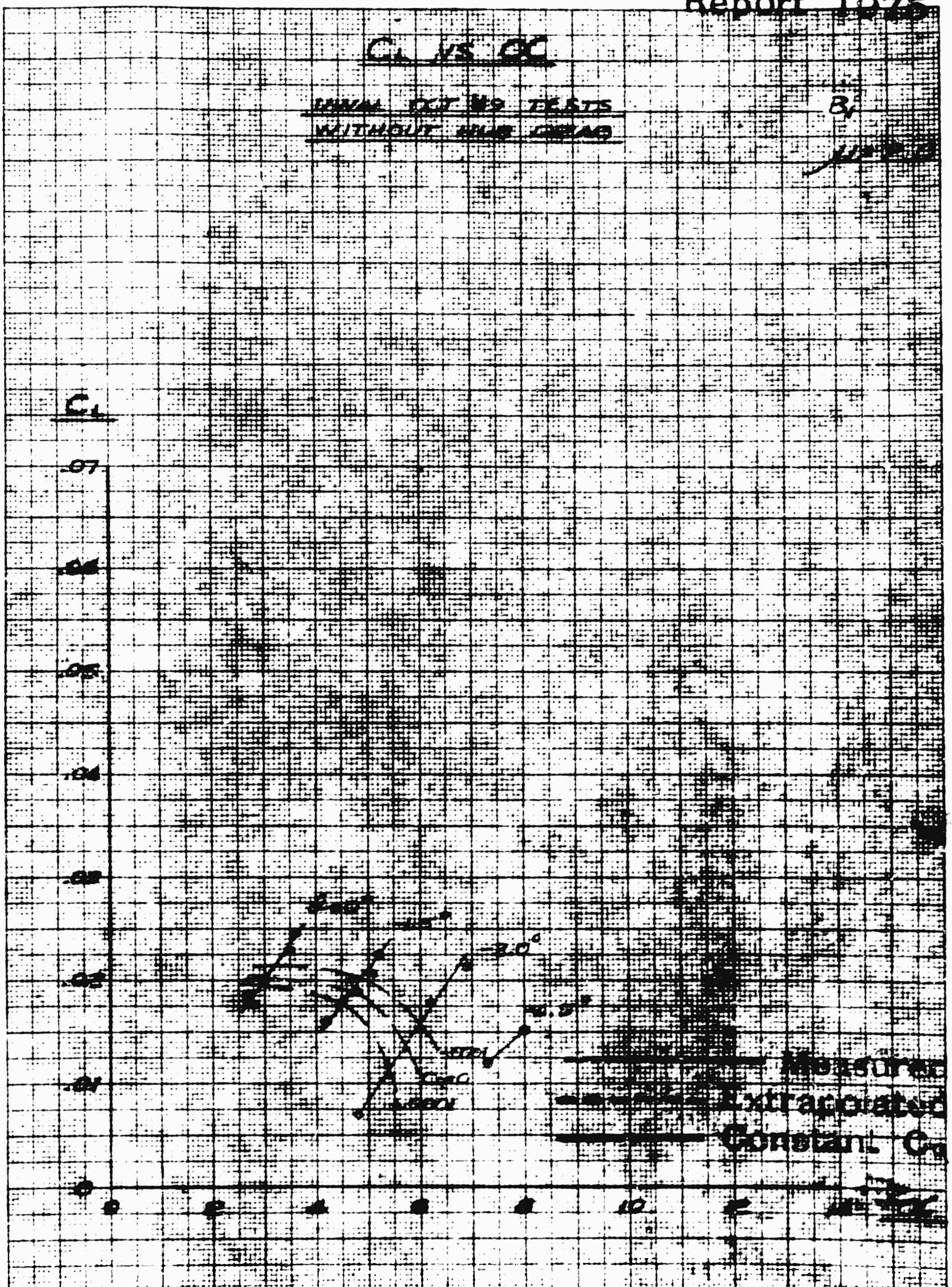
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.



KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy.

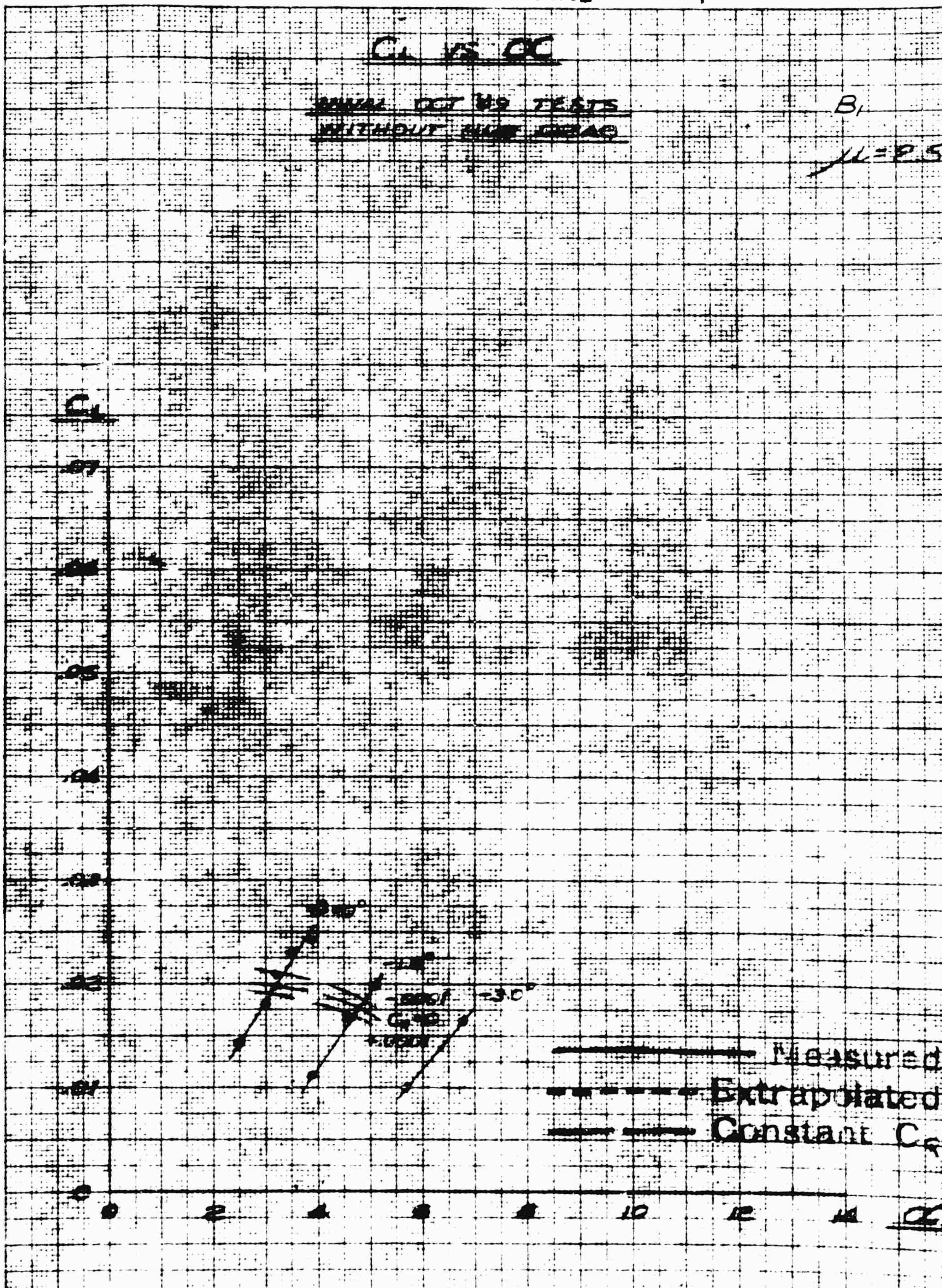


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

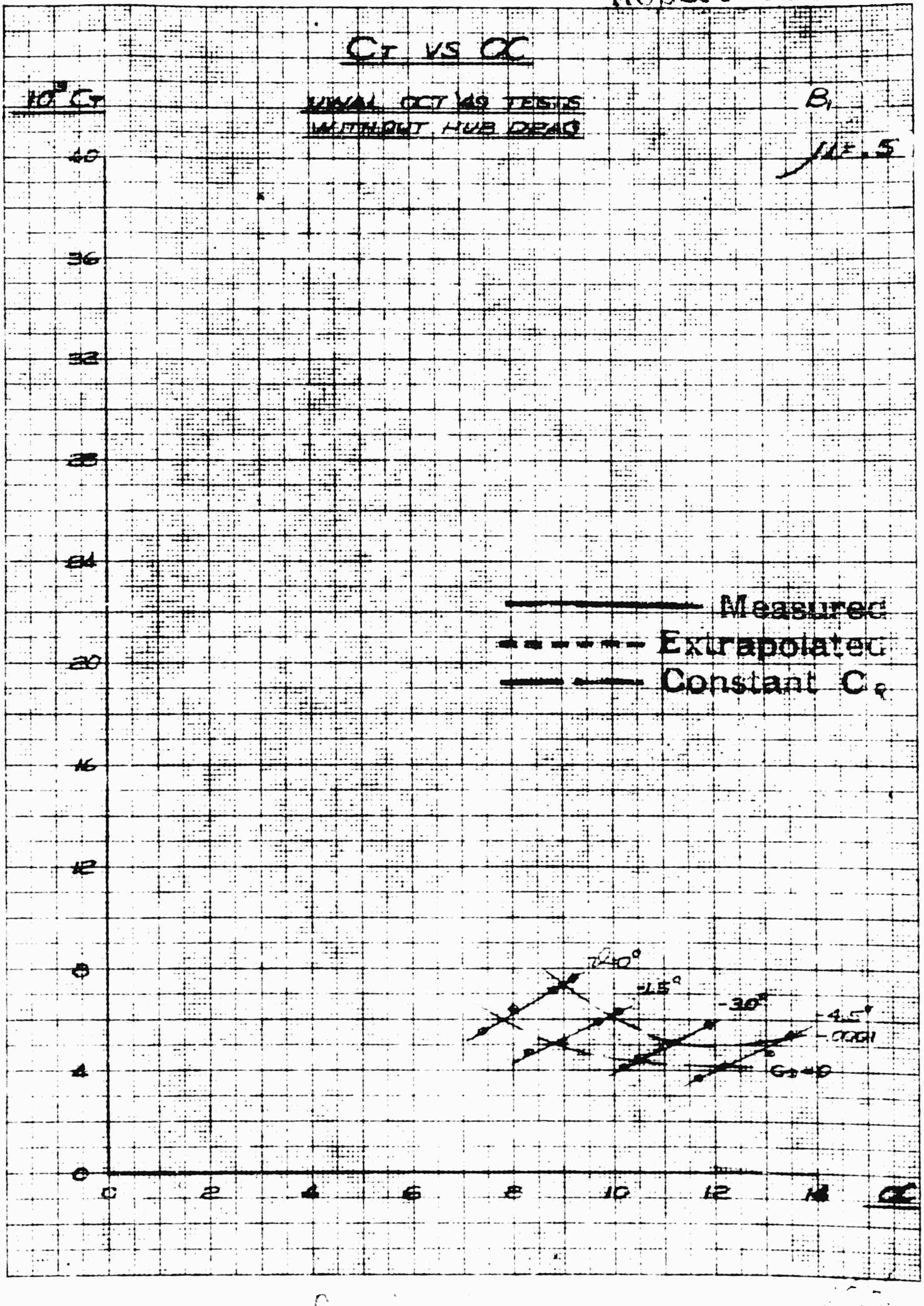


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

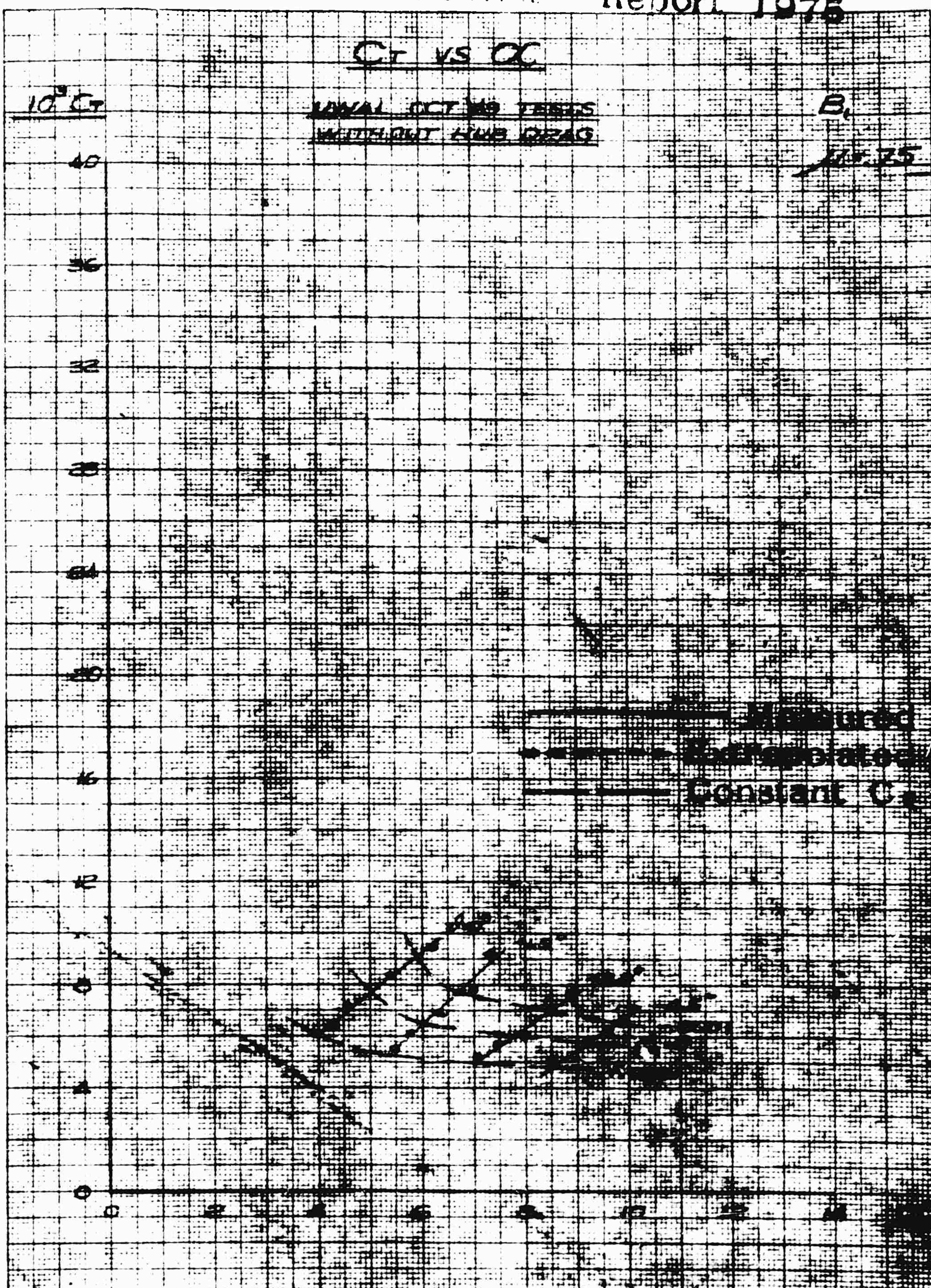
KEX
12-13-49



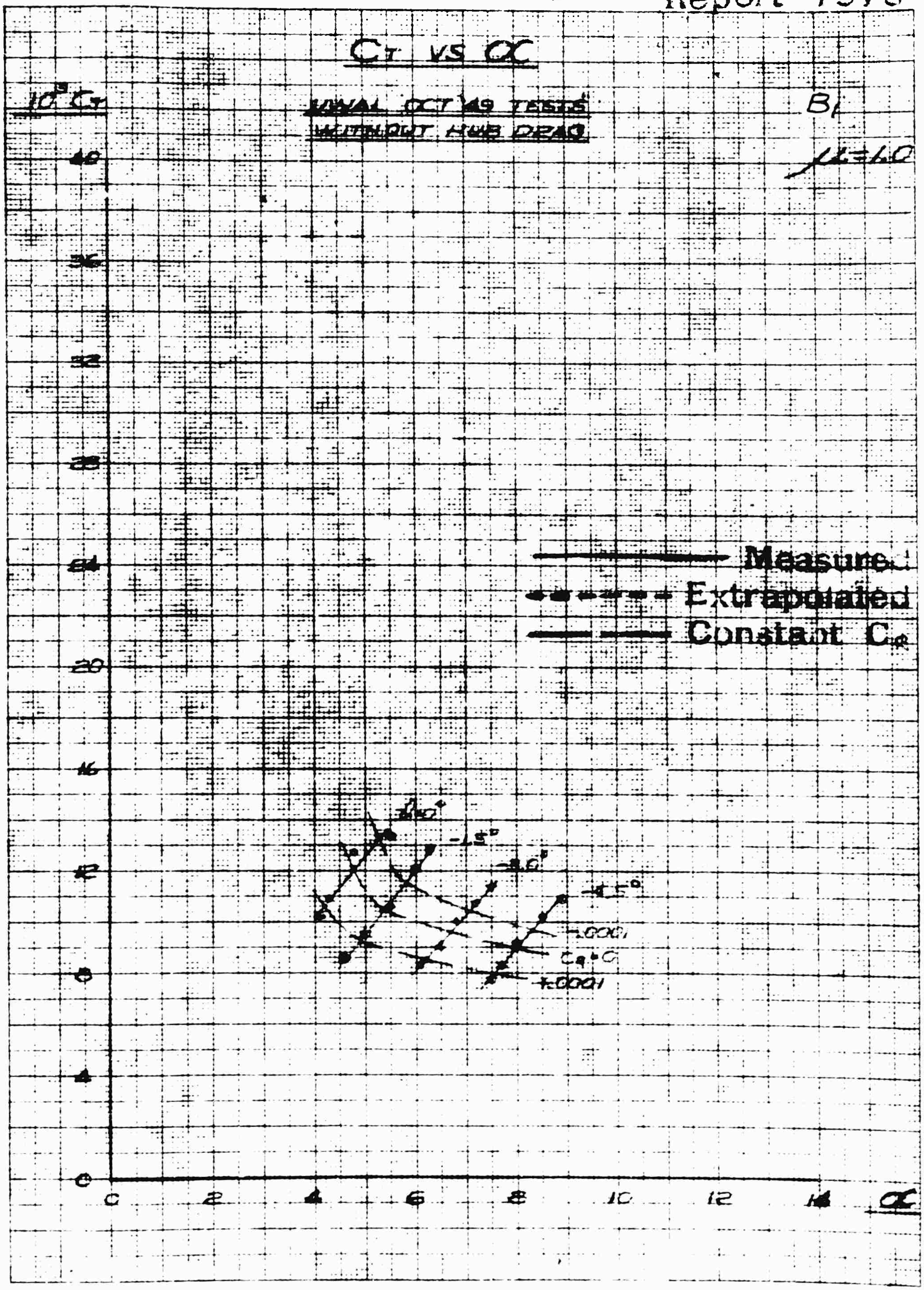
KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy.



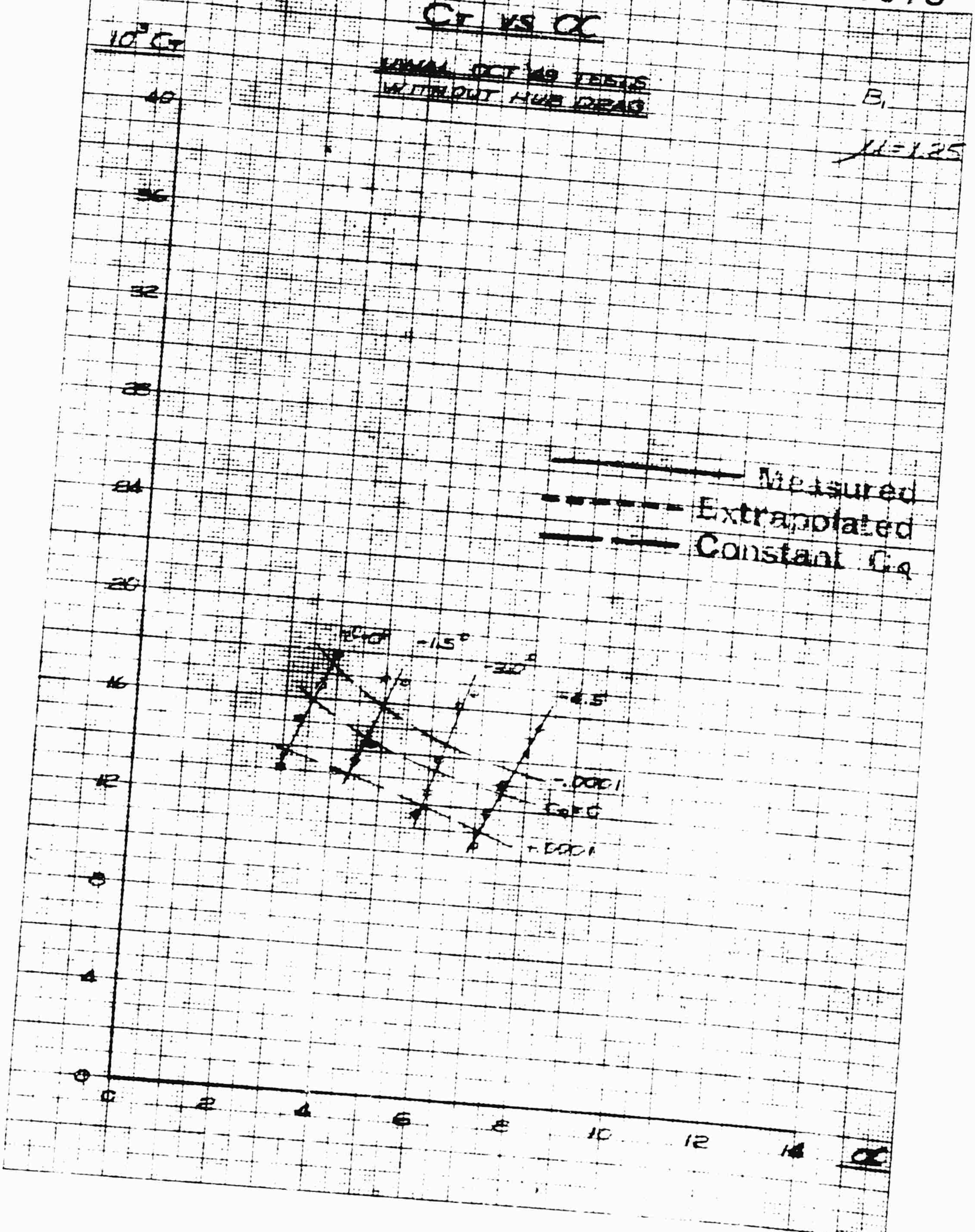
KEUFFEL & ESSER CO.
Millimeters, 5 mm. lines accented, cm. lines heavy



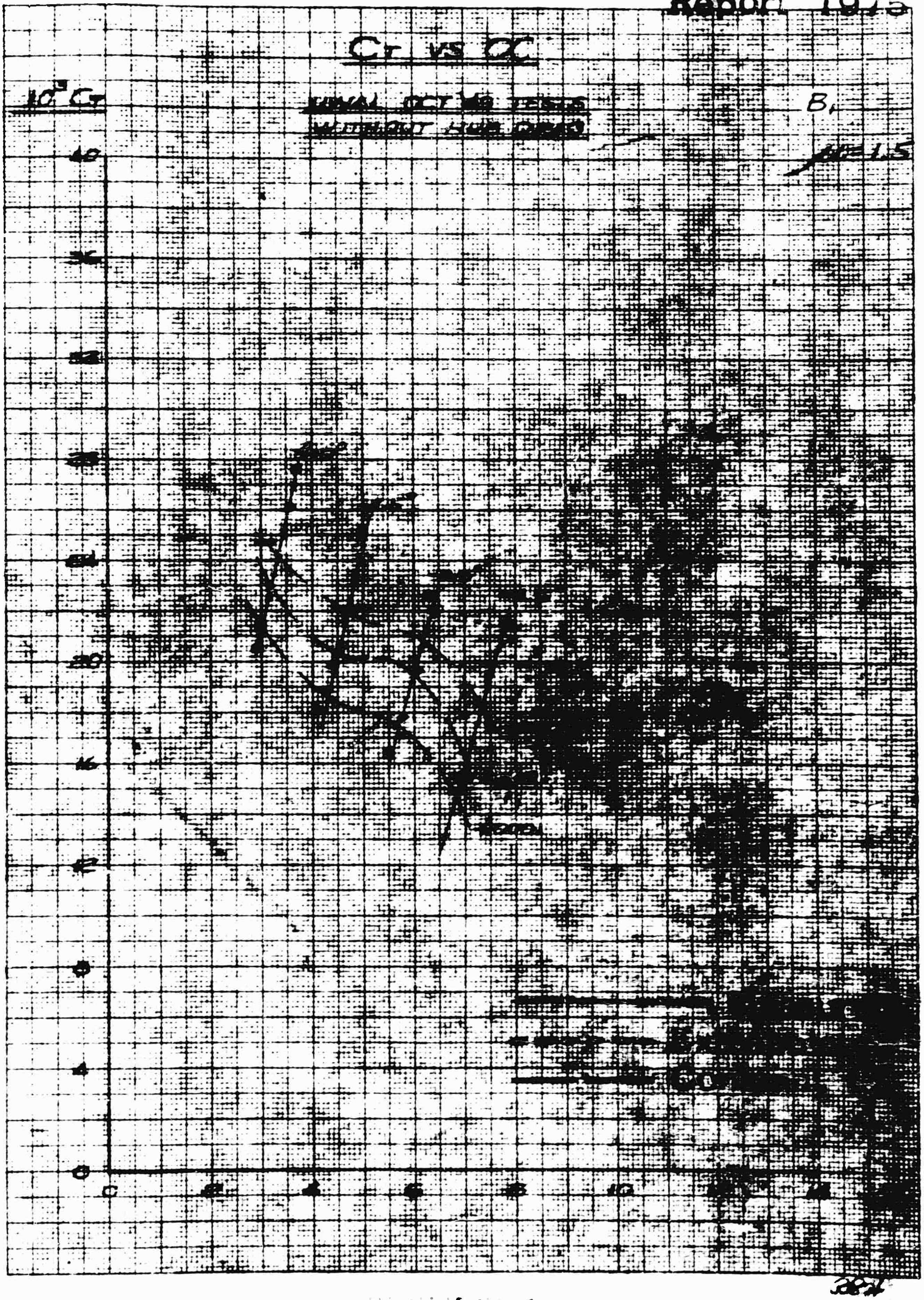
KEUFFEL & ESSER CO.
No. 359-11. Millimeters, 5 mm lines accented cm lines heavy.



KEUFFEL & ESSER CO.
No 359 14. Millimeters, 5 mm lines accented cm lines heavy.

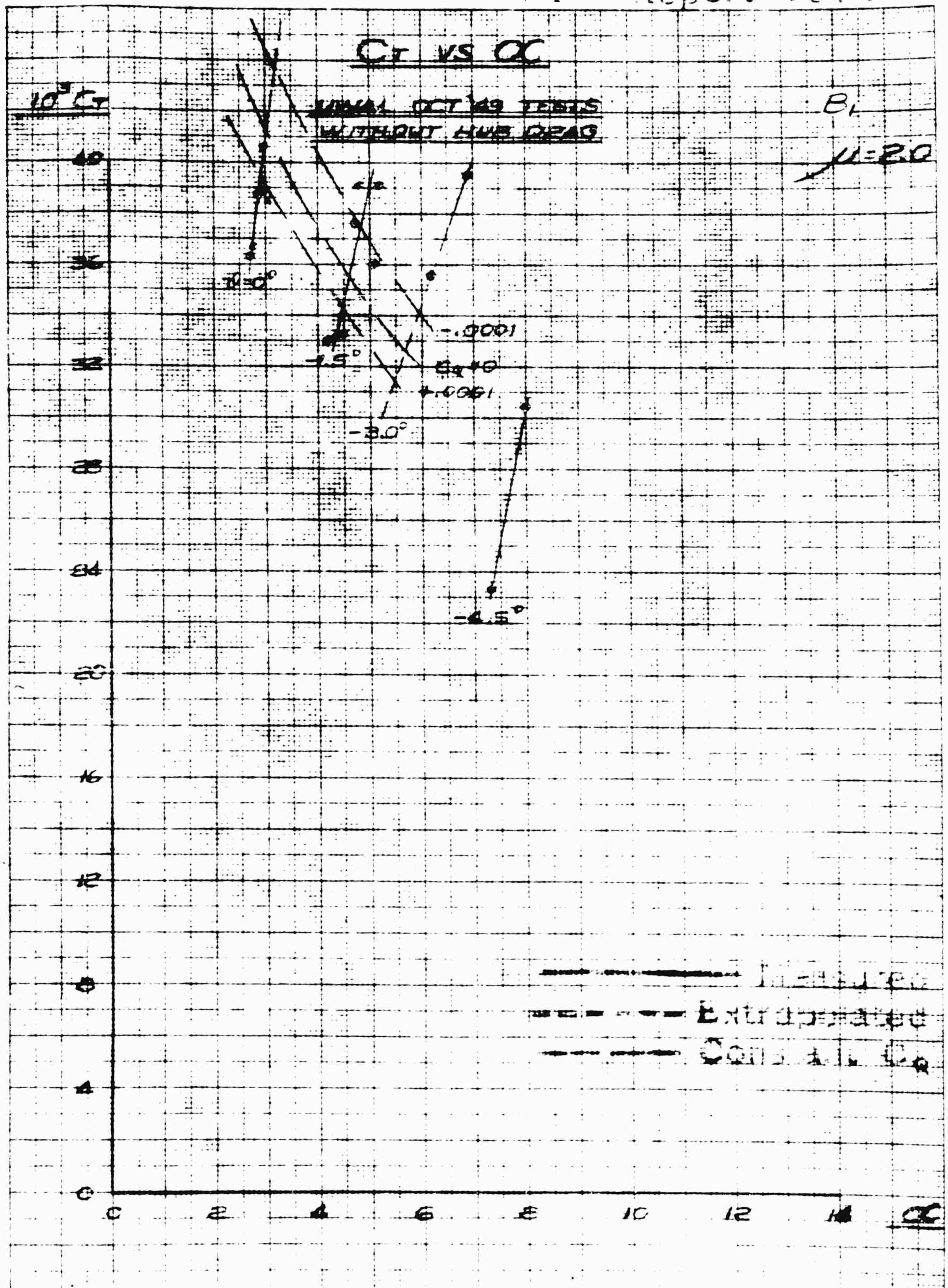


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

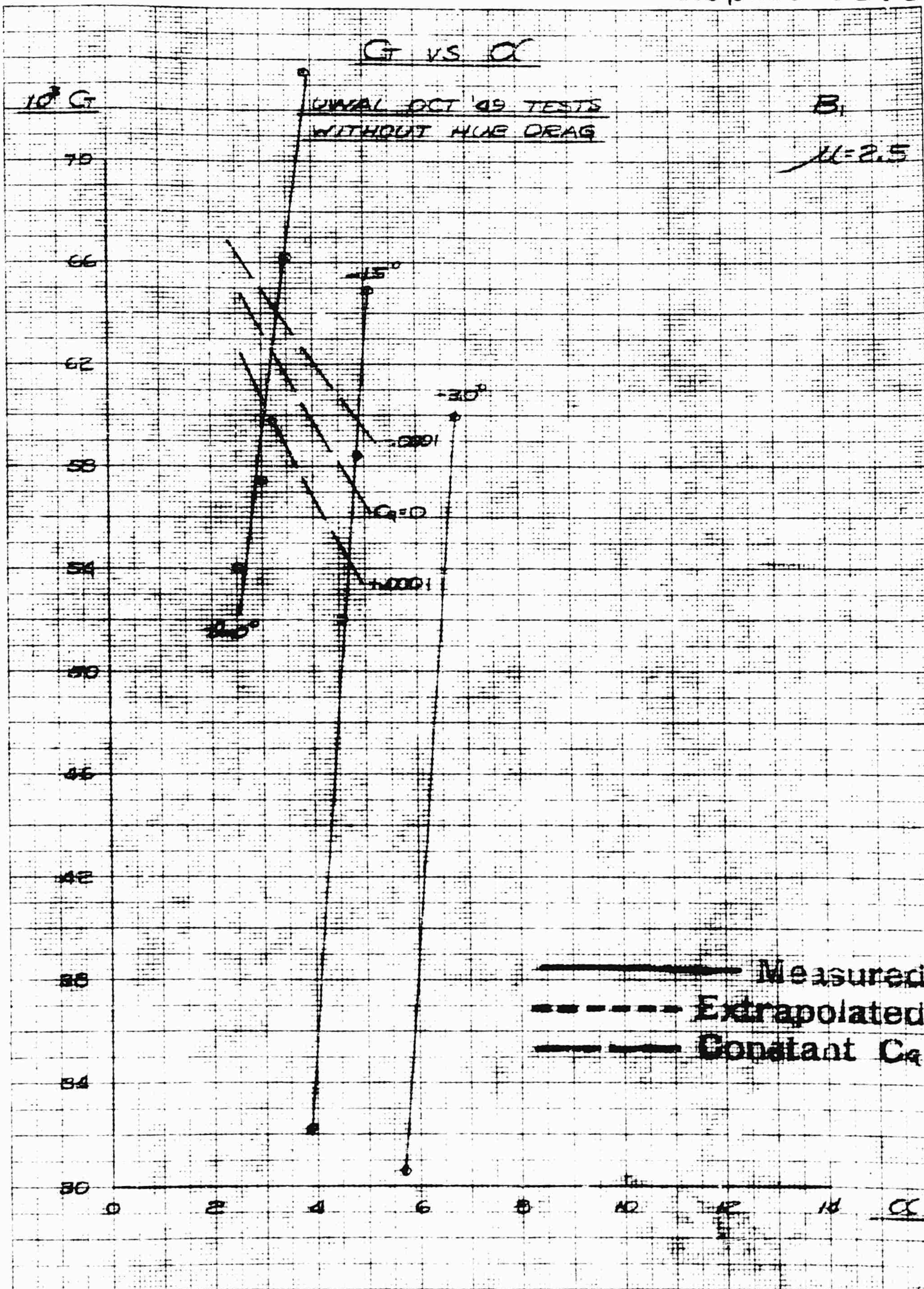


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

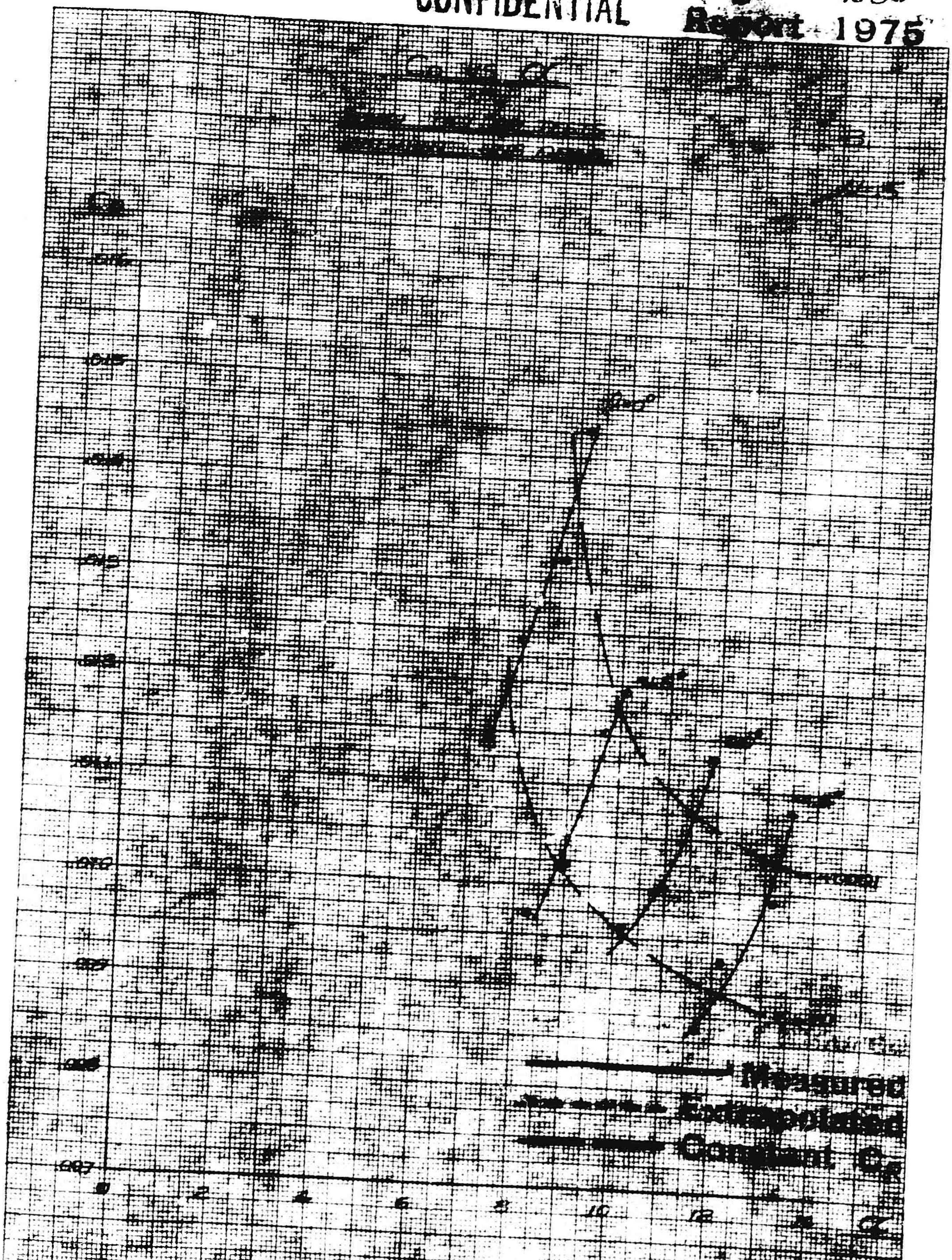
12-13-49

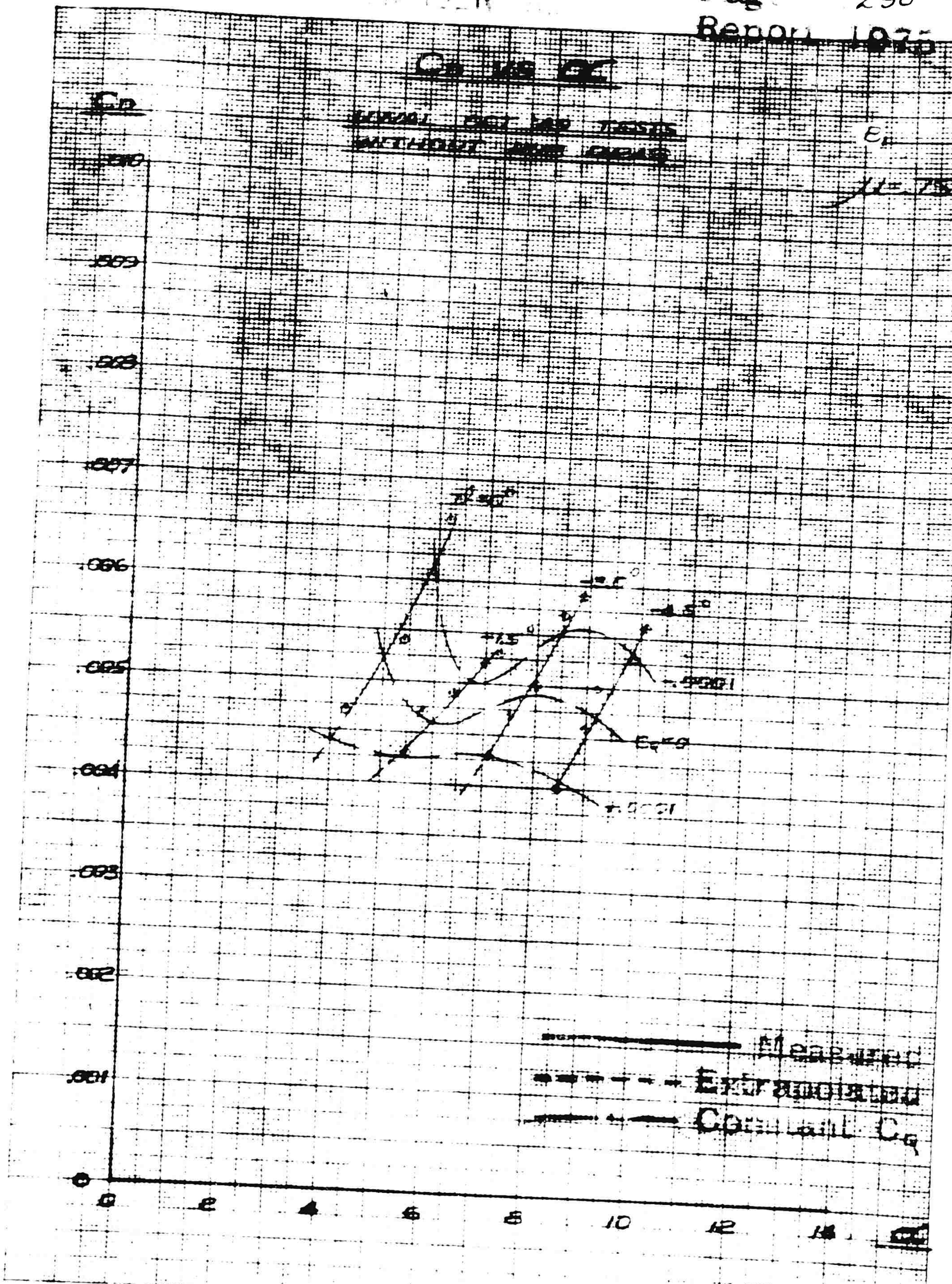


KEUFFEL & ESSER CO.
No. 359-14 Millimeter, 5 mm lines accented, cm lines heavy

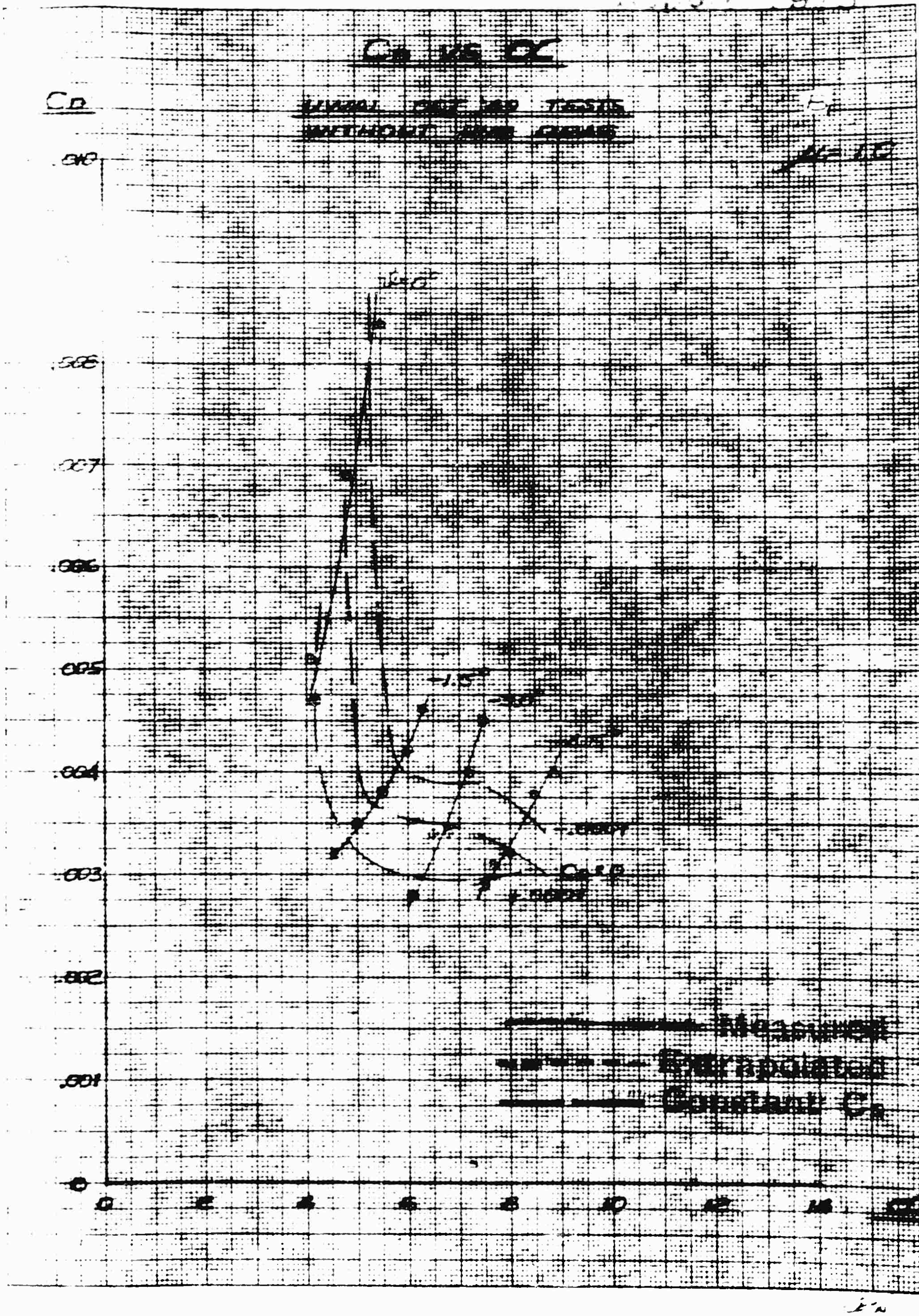

C_T vs α
$10^3 C_T$
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_1
$\mu = 2.5$
70
66
62
58
54
50
46
42
38
34
30
0
2
4
6
8
10
12
14
α
-15°
-30°
-.0001
$C_Q = 0$
+.0001
0°
Measured
Extrapolated
Constant C_Q

CONFIDENTIAL

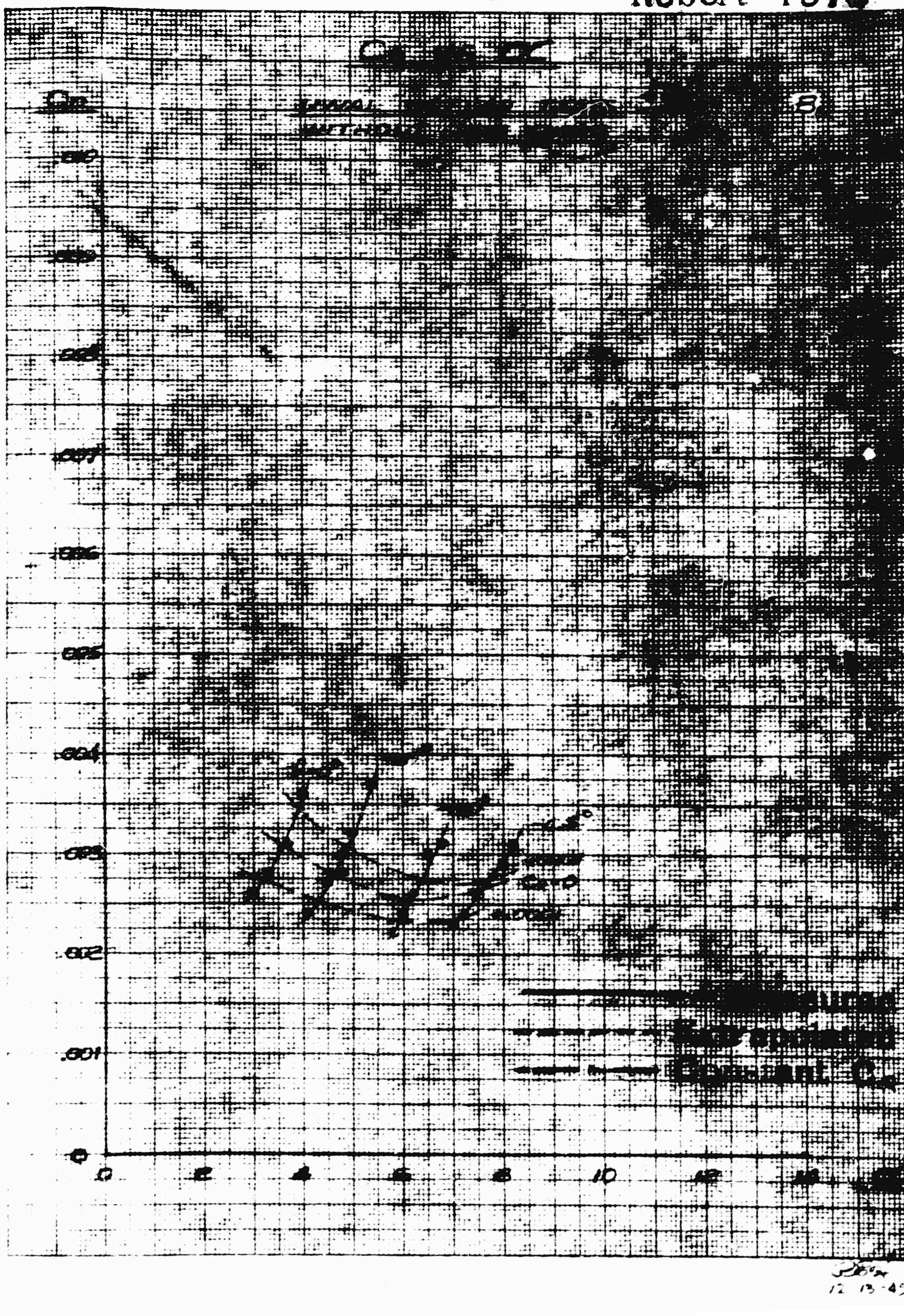




KEUFFEL & ESSER CO.



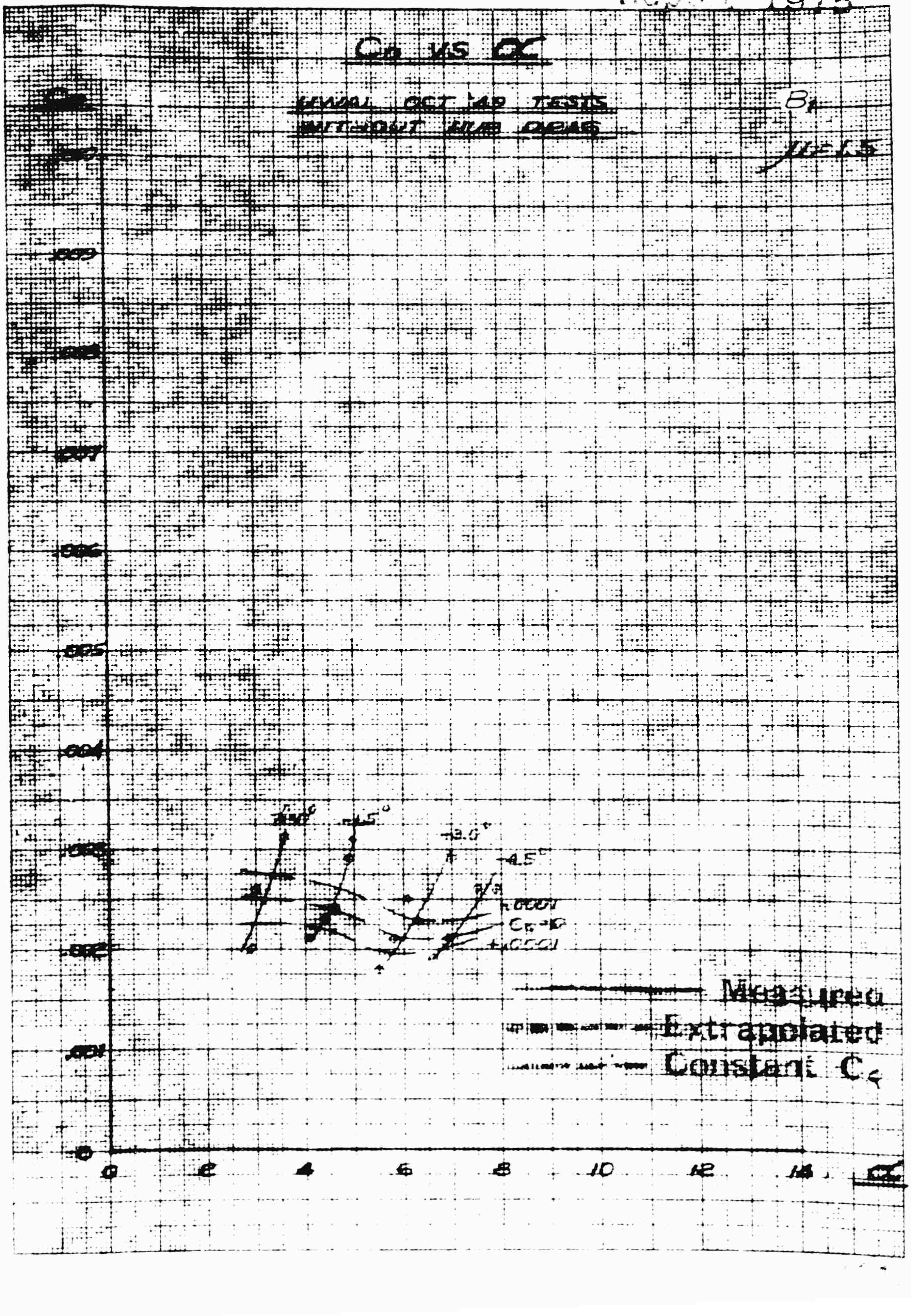
KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy



12-13-49

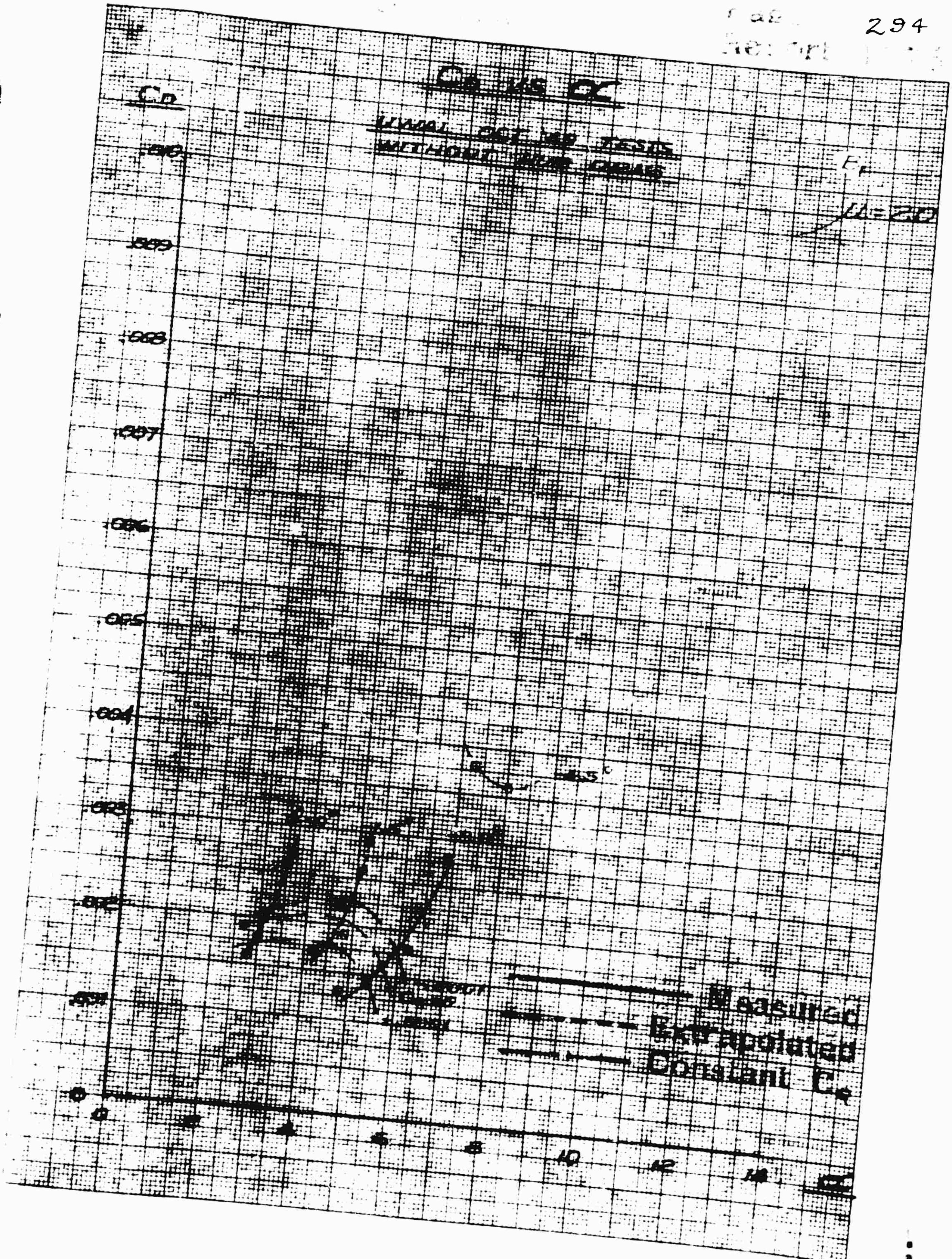
CONFIDENTIAL

Page 293
Report 1975

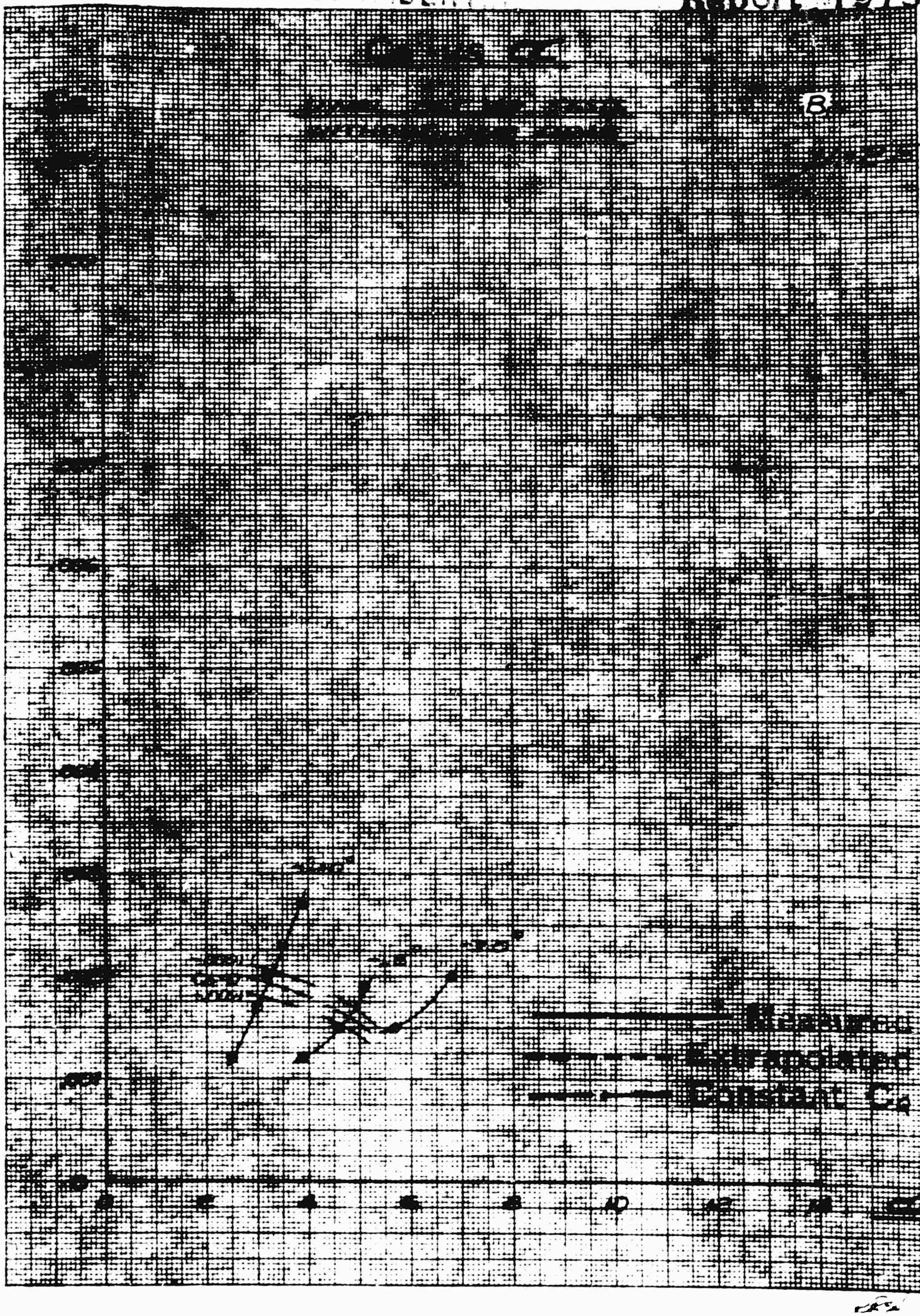


KEUFFEL & ESSER CO.

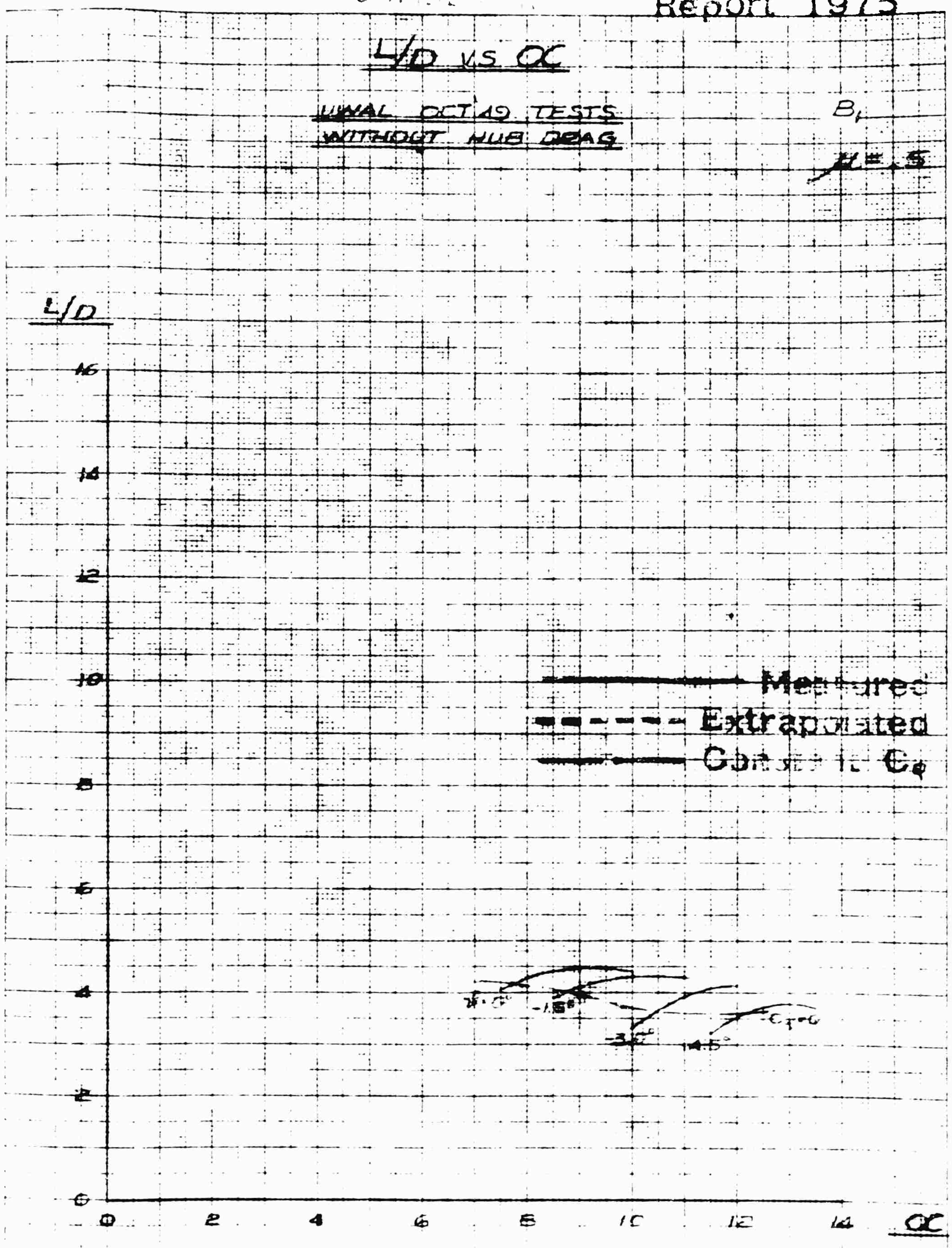
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy


C_D
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
0
0
2
4
6
8
10
12
14
α
$\mu = 2.0$
Measured
Extrapolated
Constant C_L

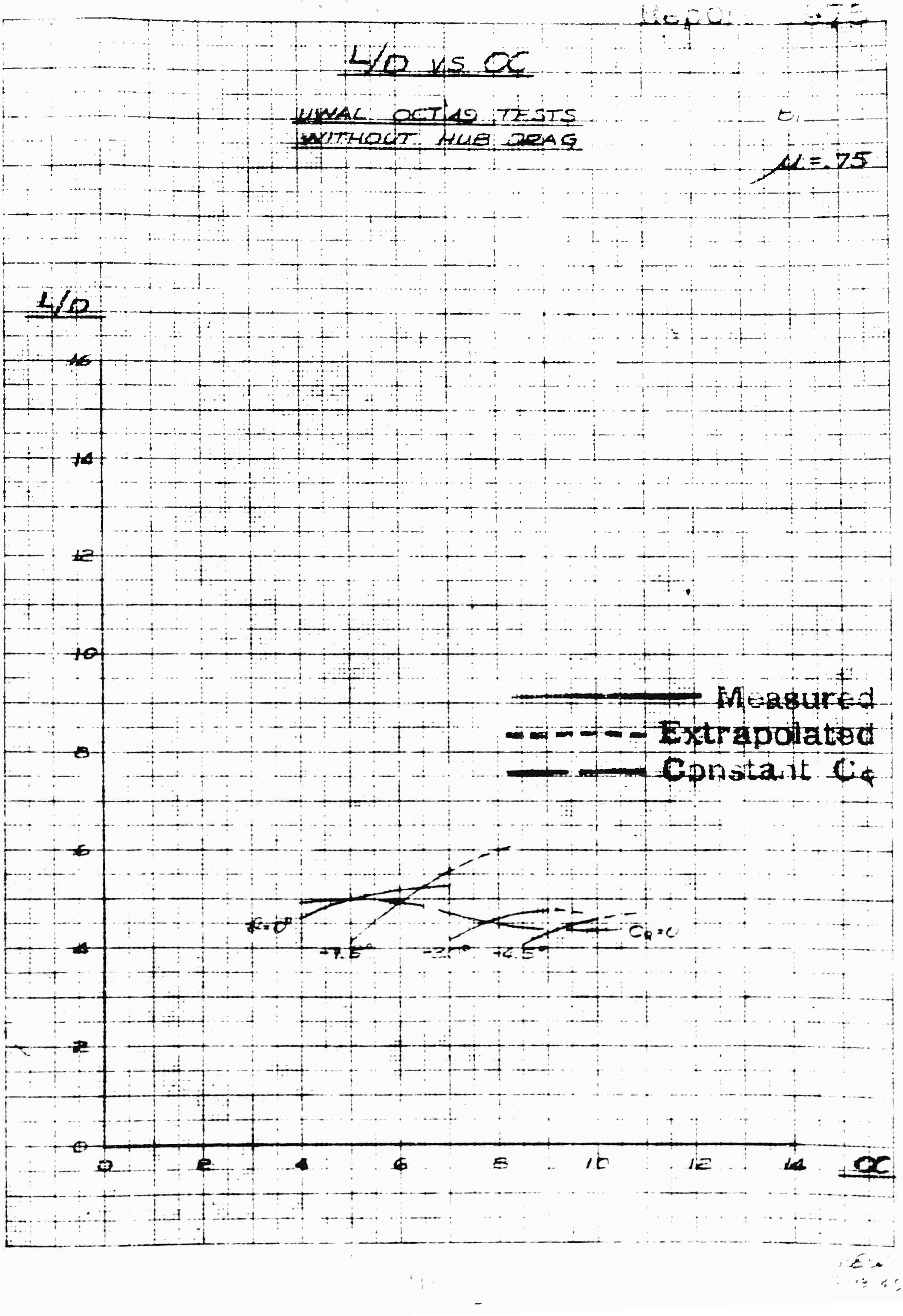
CONFIDENTIAL



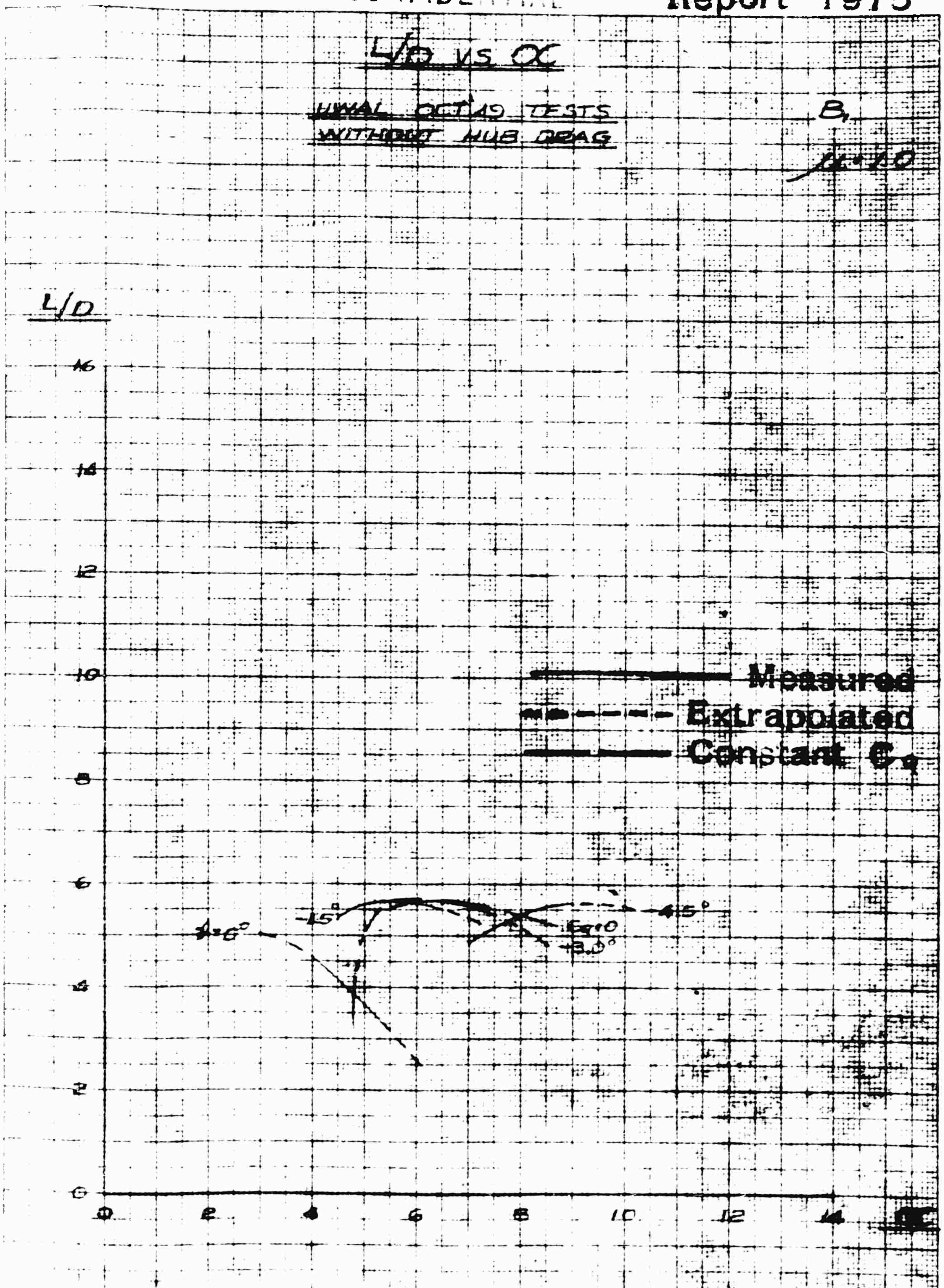
KEUFFEL & ESSER CO.
No. 1-914 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy

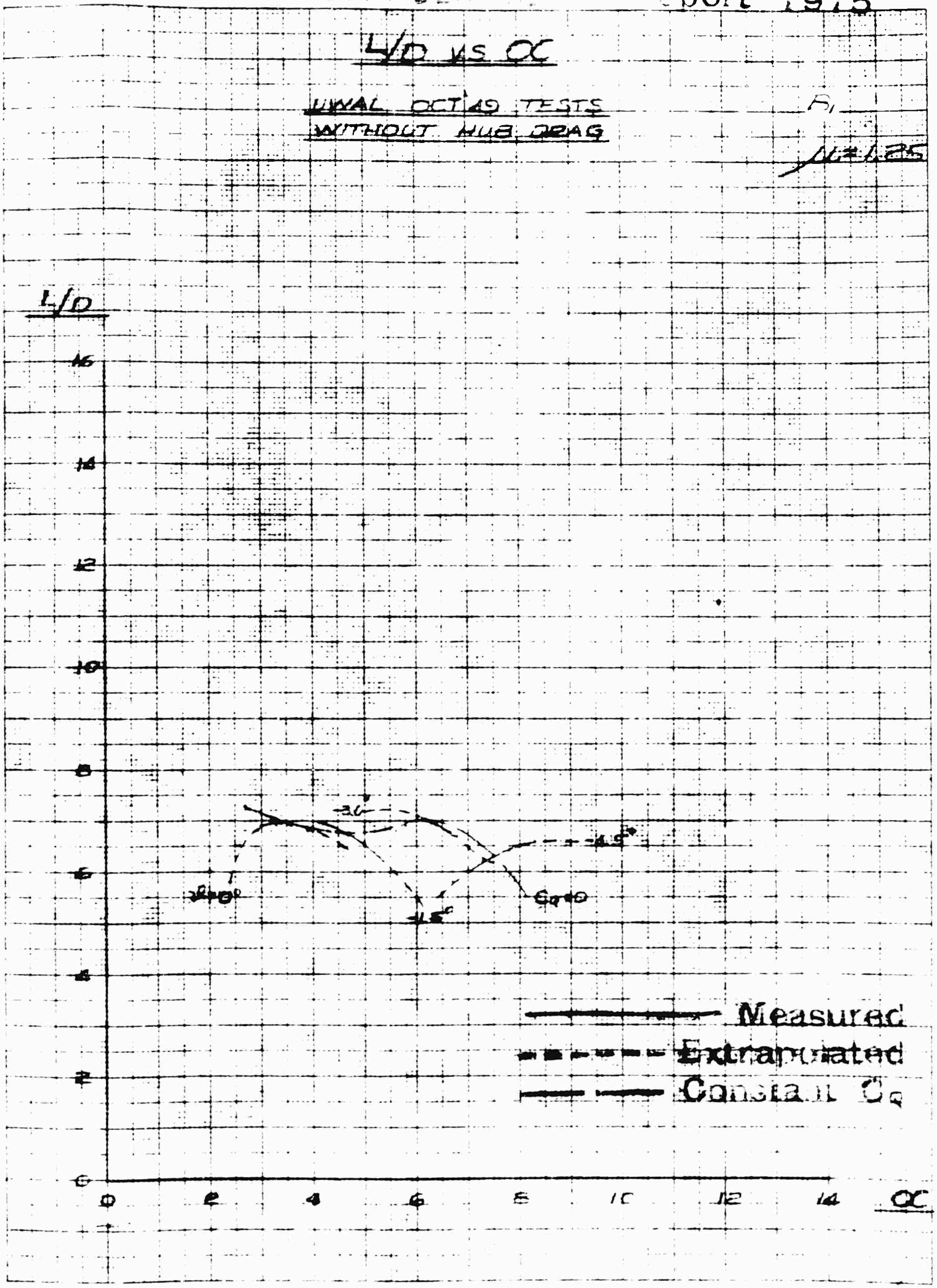

L/D vs α
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
μ = .75
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant Cℓ
Cℓ = 0

CONFIDENTIAL

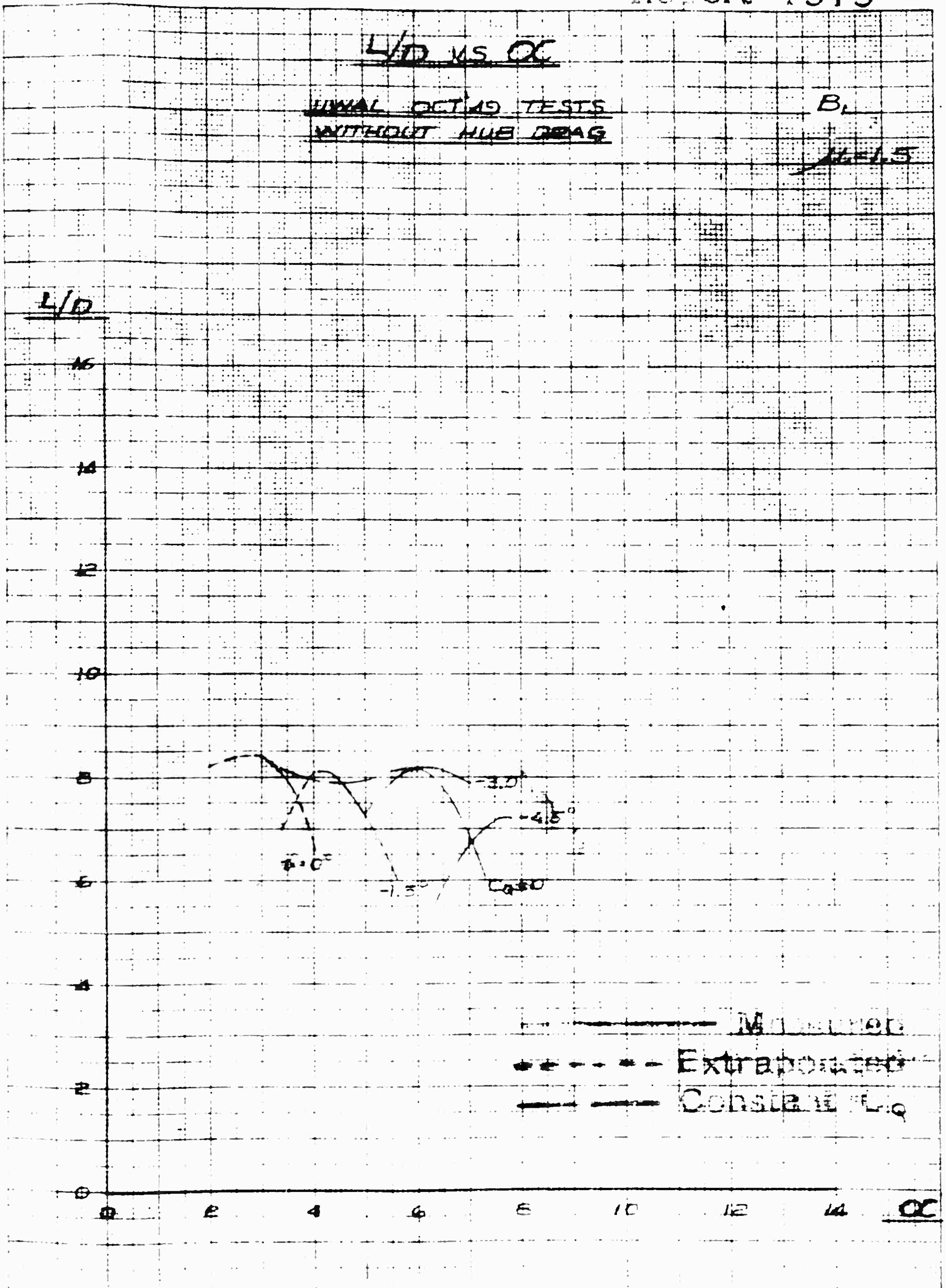


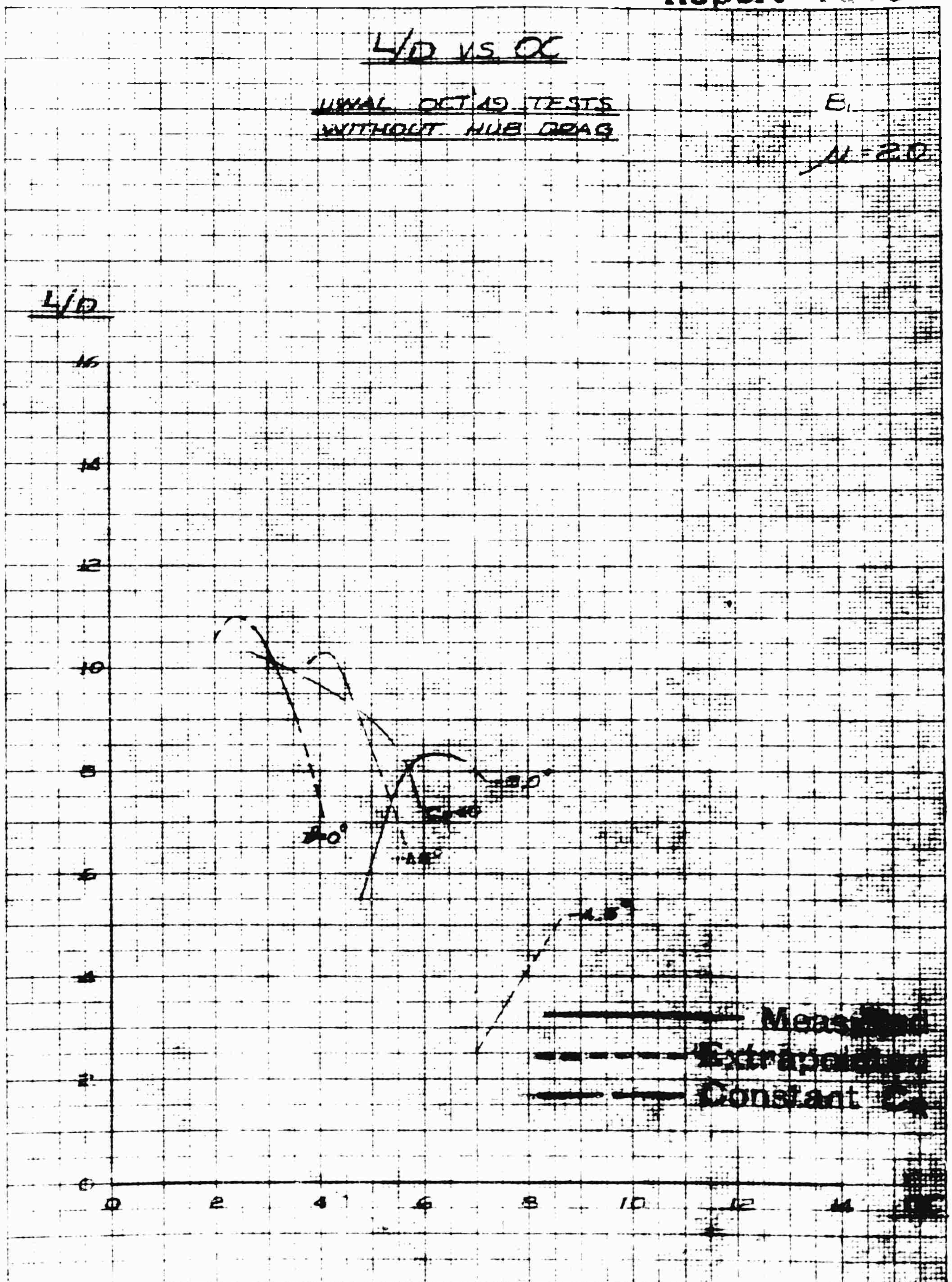
12-15-49

KEUFFEL & ESSER CO
CONFIDENTIAL



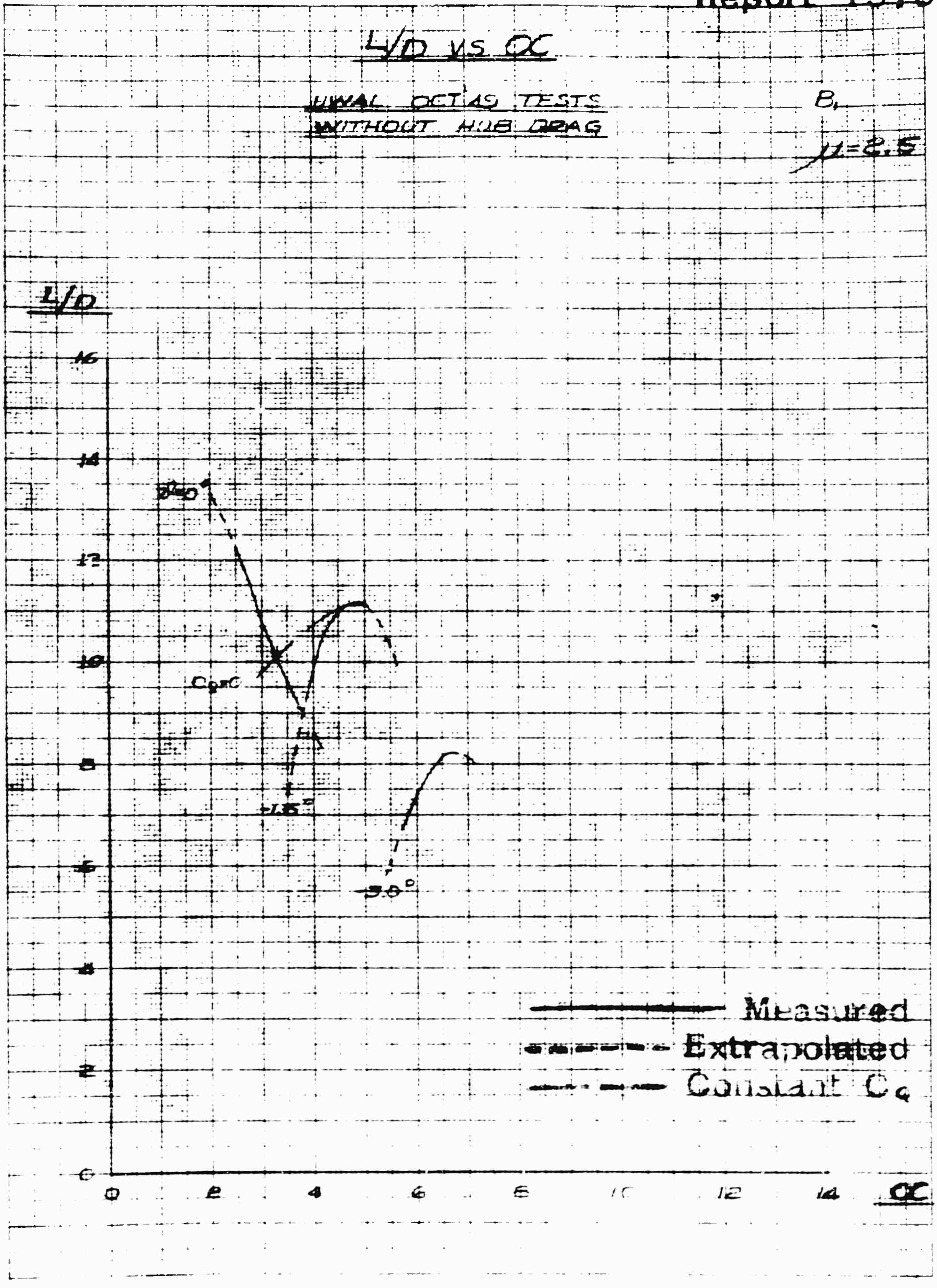
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

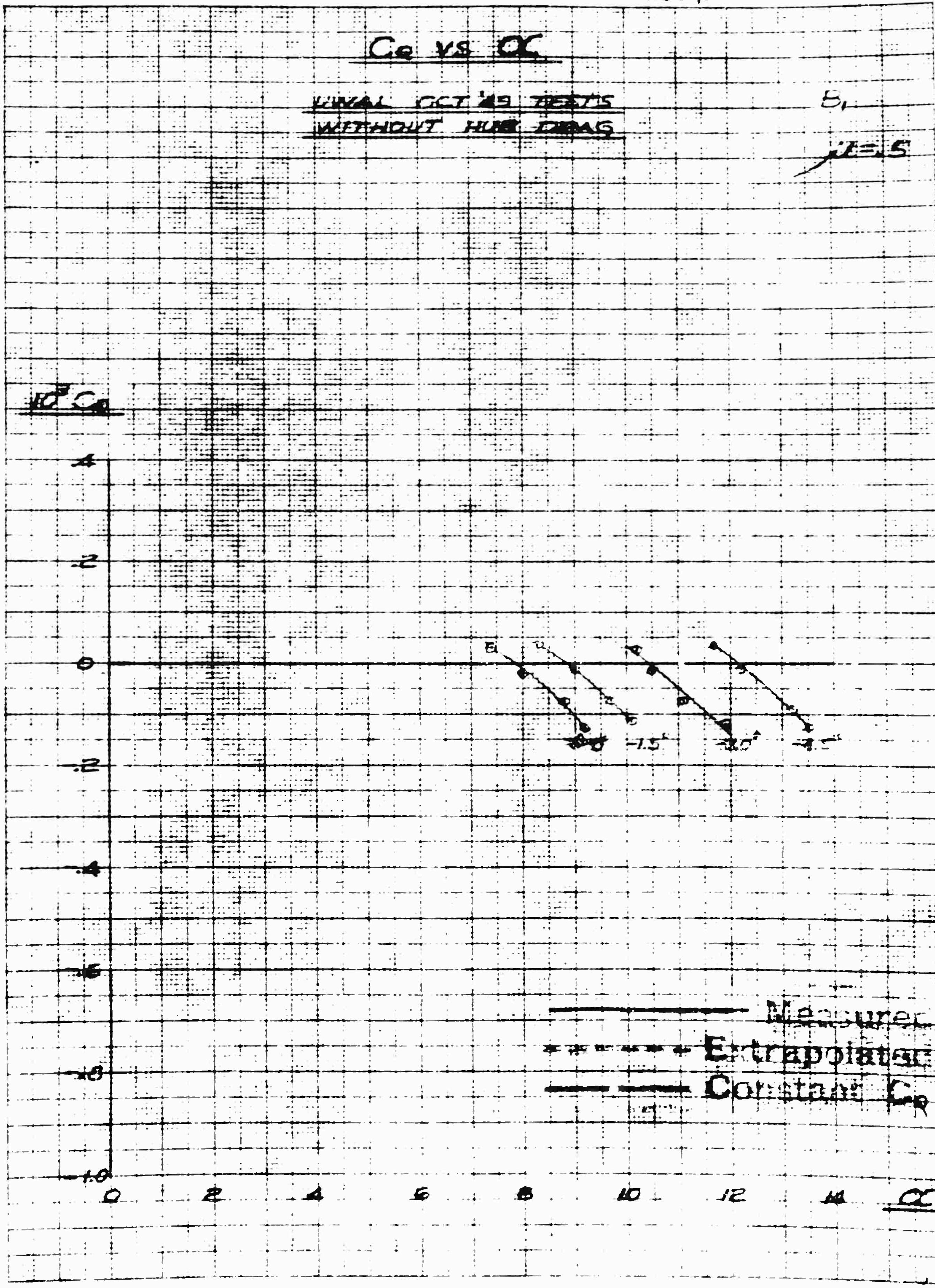

L/D vs. α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B₁
μ = 1.5
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
α
θ = 0°
-1.5°
-3.0°
-4.5°
$C_Q = 0$
Measured
Extrapolated
Constant C_Q

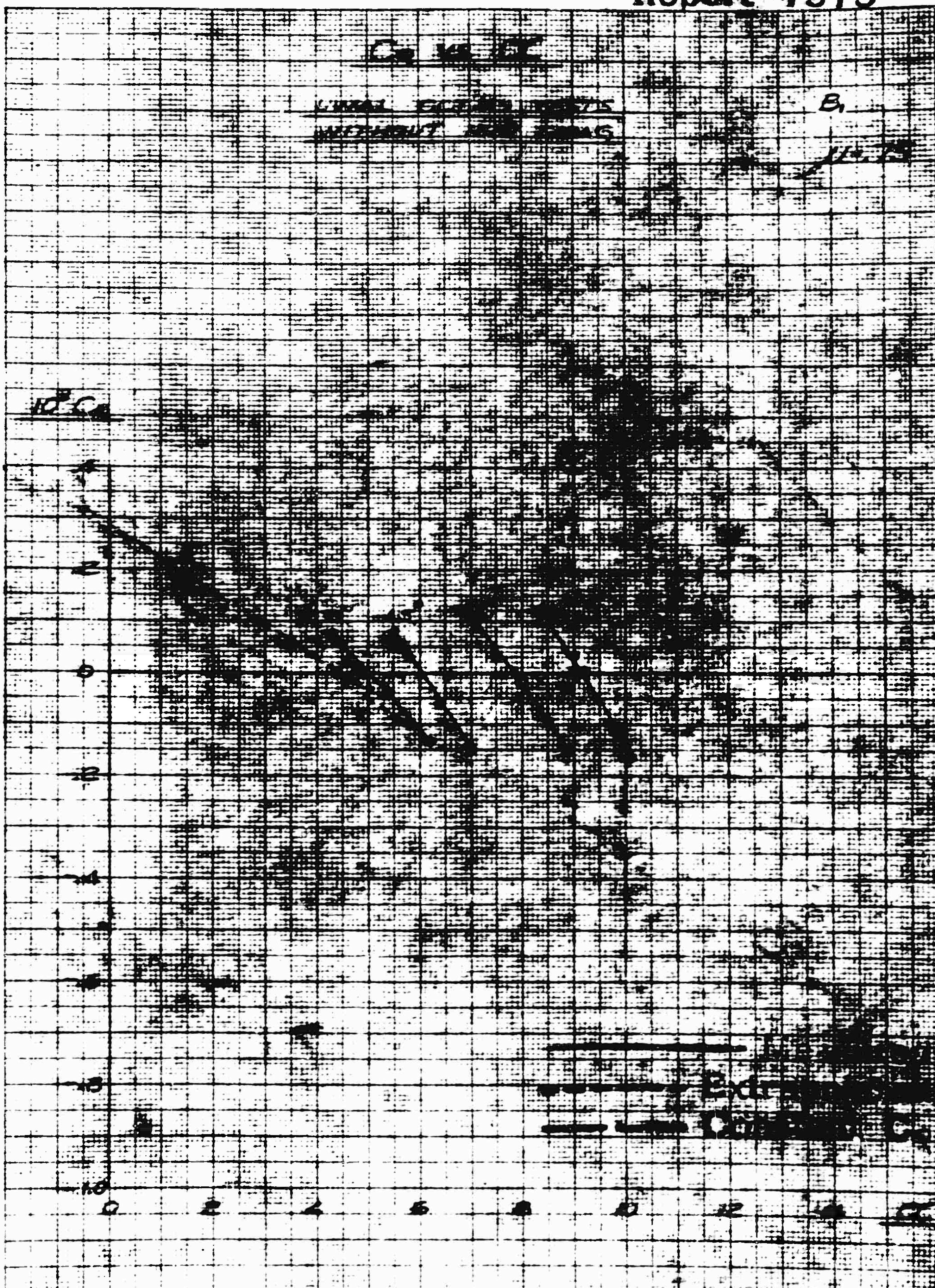


KEUFFEL & ESSER CO.
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy

12-13-49

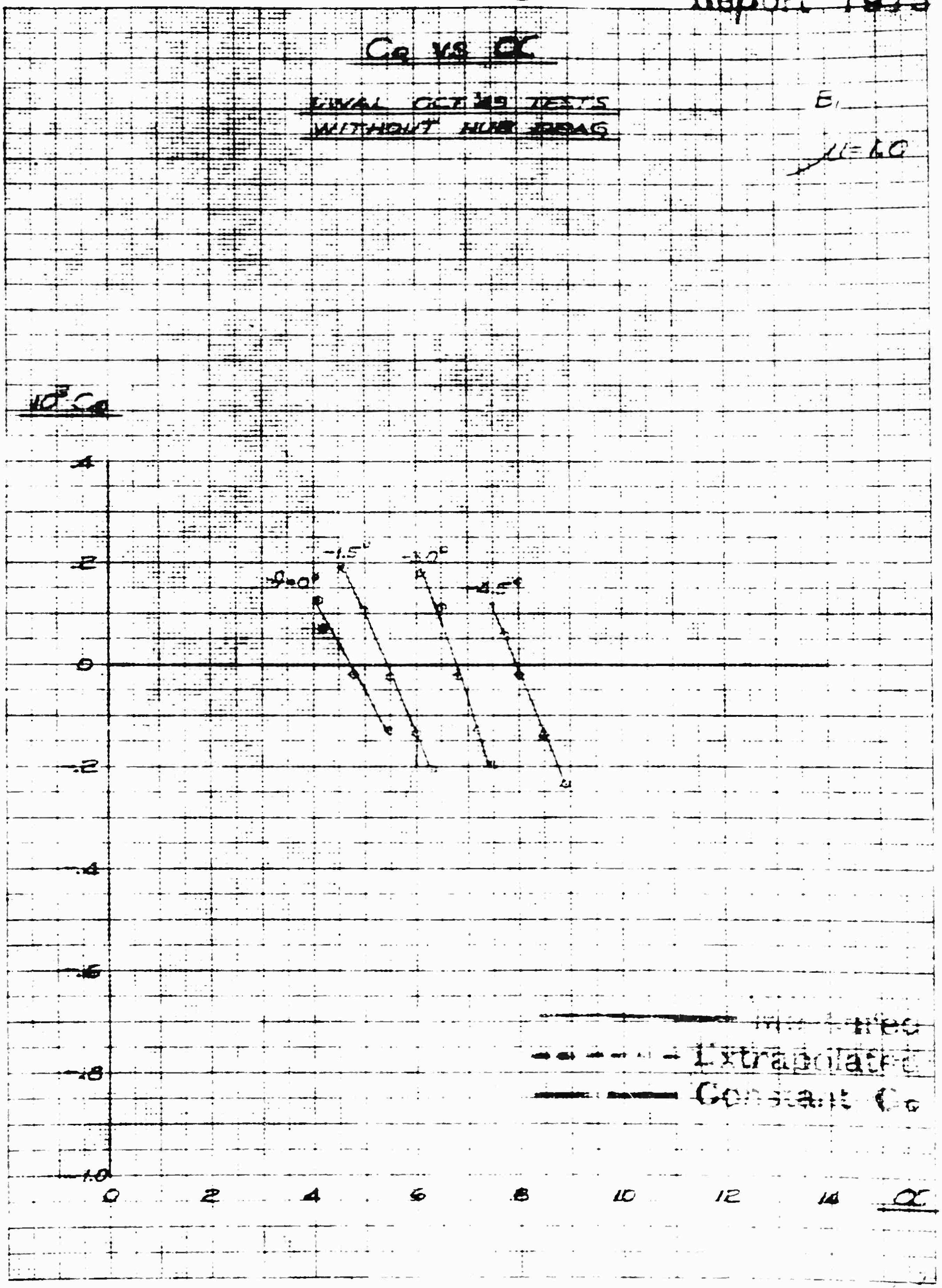

L/D VS OC
UWAL OCT 49 TESTS
WITHOUT HUB DRAG
B1
μ=2.5
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
Cq=C
-1.5°
-3.0°
Measured
Extrapolated
Constant Cq


C_e vs α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B_1
$J = .5$
$10^3 C_e$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
-1.5°
-2.0°
Measured
Extrapolated
Constant C_p

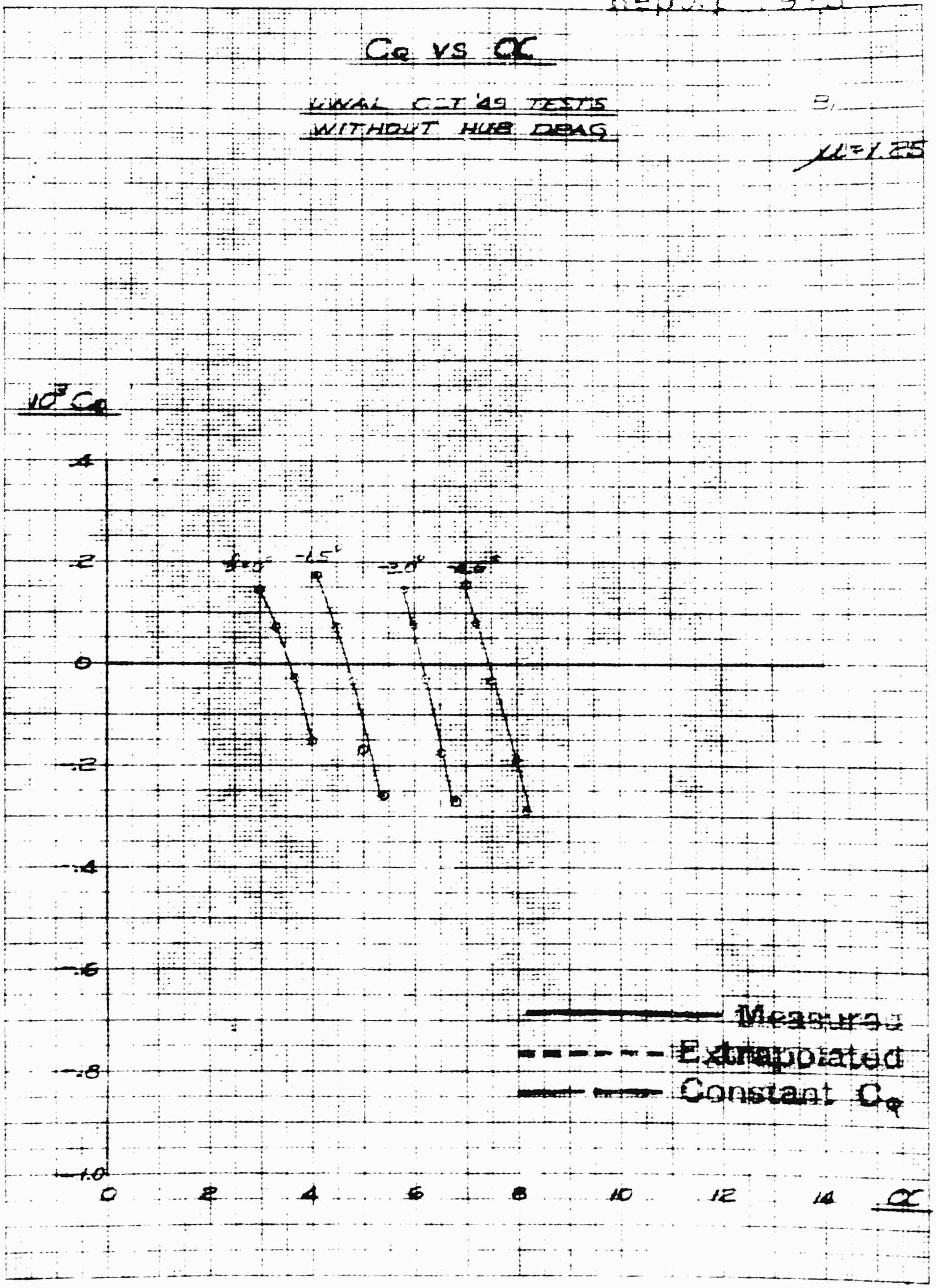


KEUFFEL & ESSER CO.

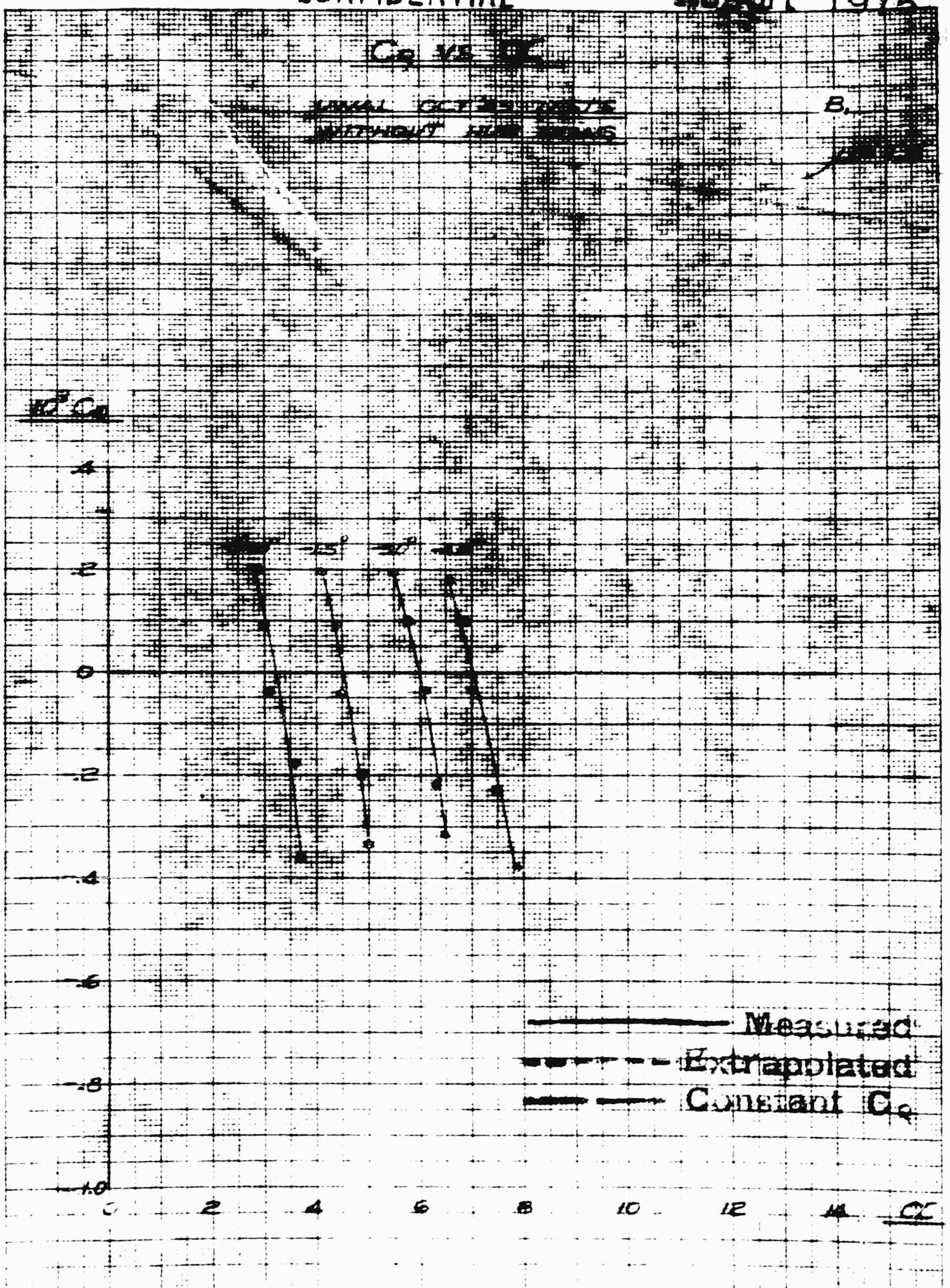
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy.


Cq vs α
FINAL OCT '49 TESTS
WITHOUT HUB DRAG
$10^3 C_q$
θ=0°
-1.5°
-3.0°
-4.5°
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
Extrapolated
Constant Cq

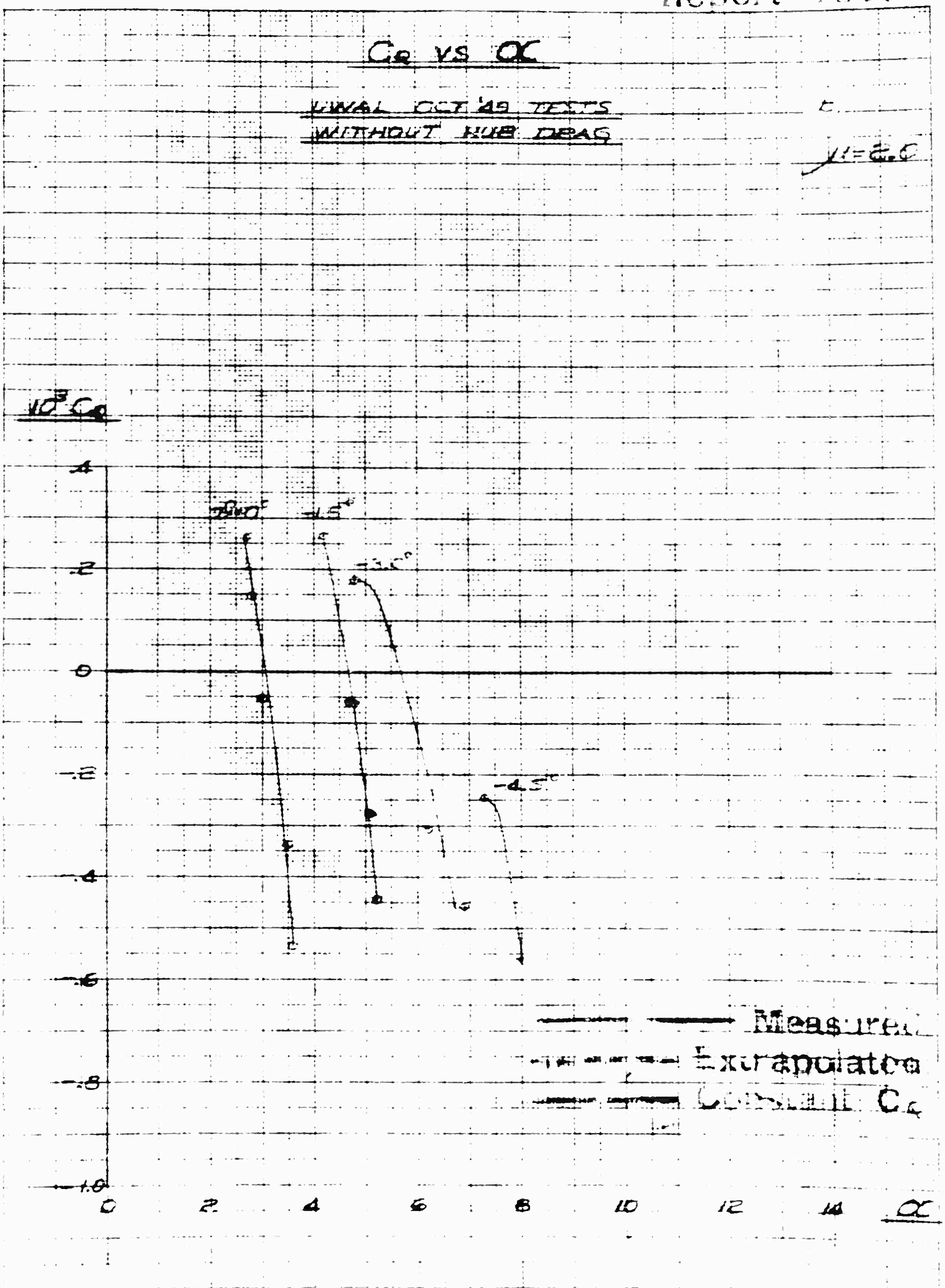
Report 1975

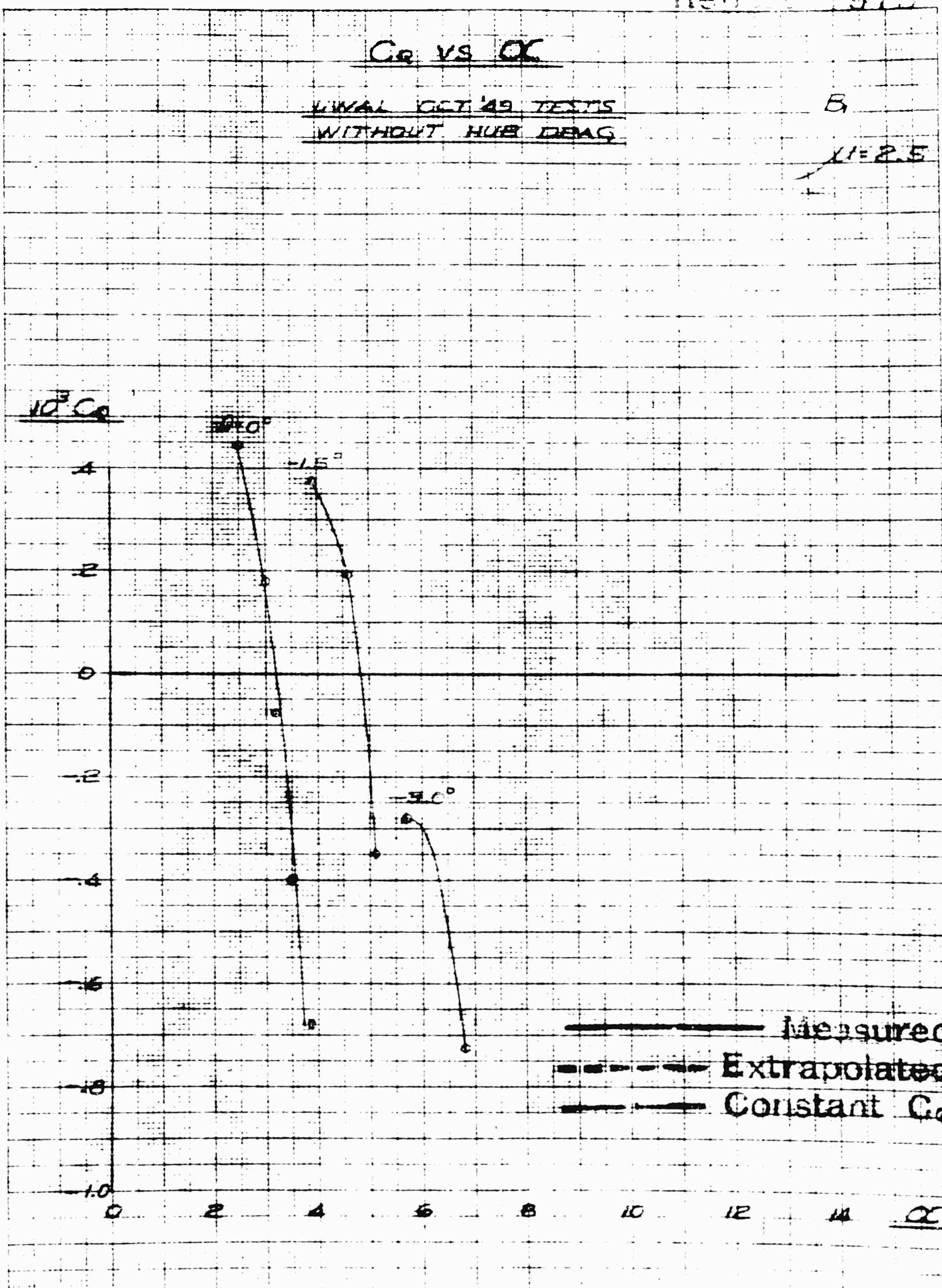


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm. lines accented, cm. lines heavy

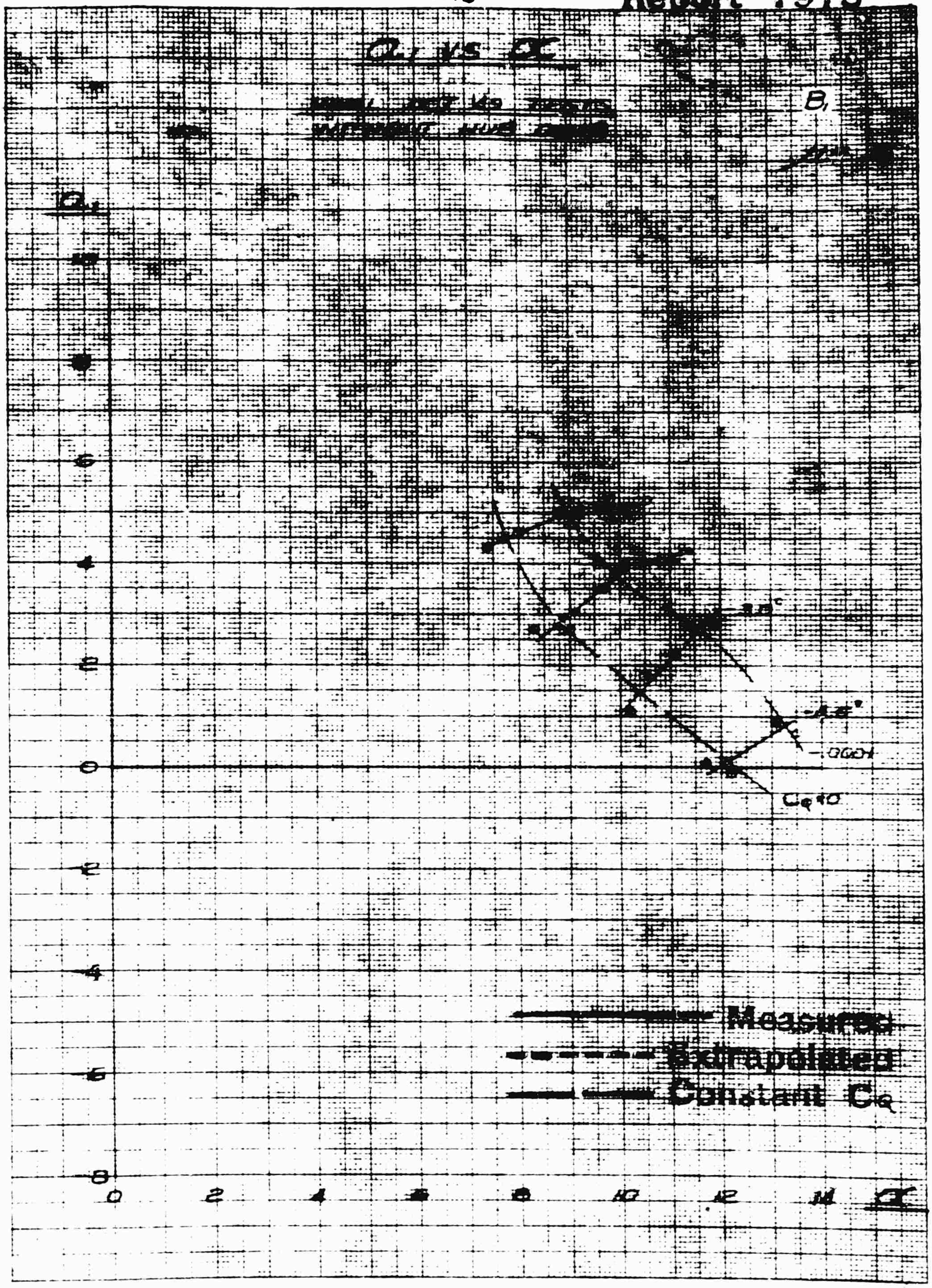


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

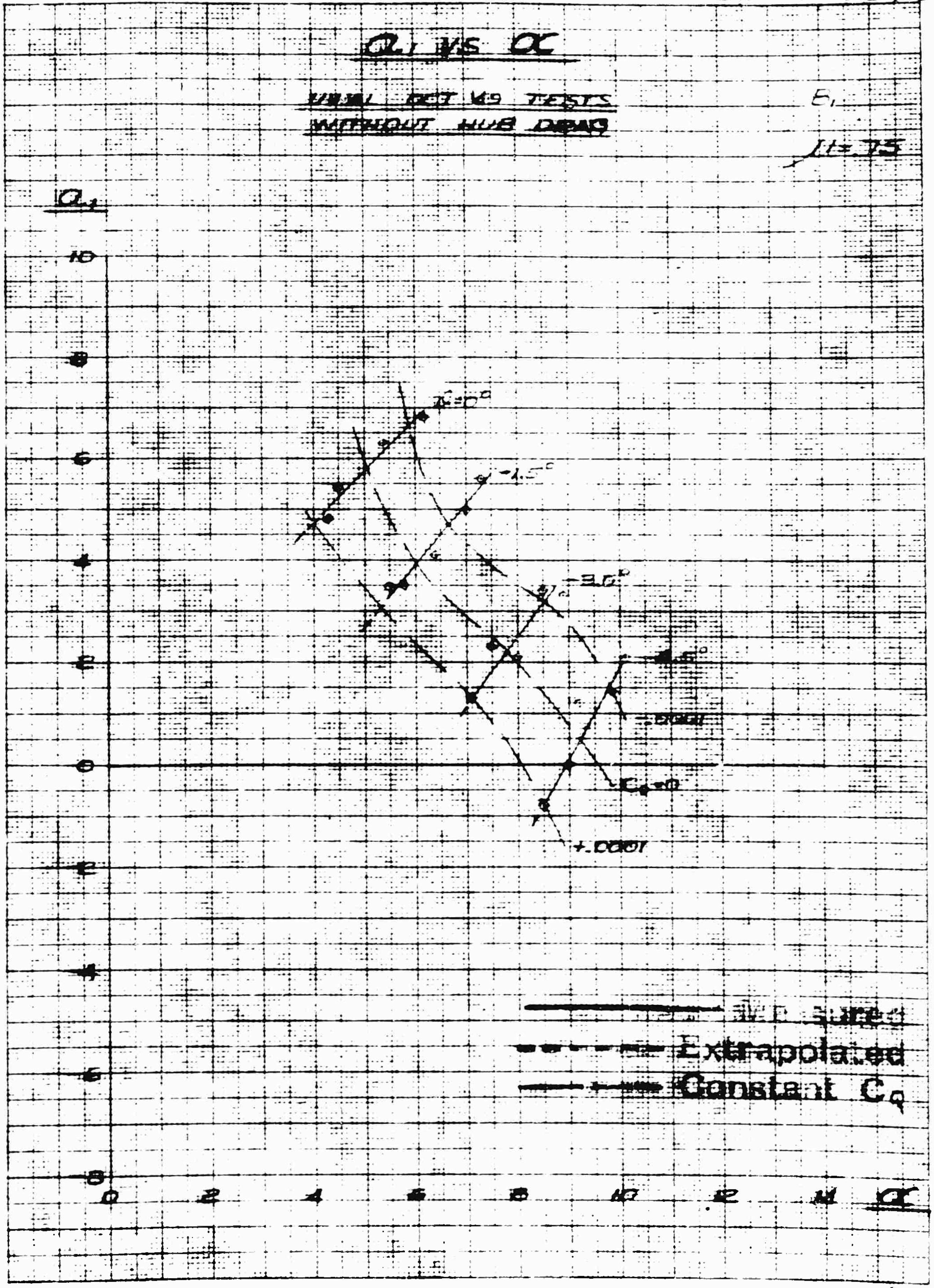

C_Q VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
μ = 2.0
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
-4.5°
Measured
Extrapolated
Constant C_L


C_Q VS α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
B
J = 2.5
$10^3 C_Q$
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
0
2
4
6
8
10
12
14
α
Measured
Extrapolated
Constant C_Q

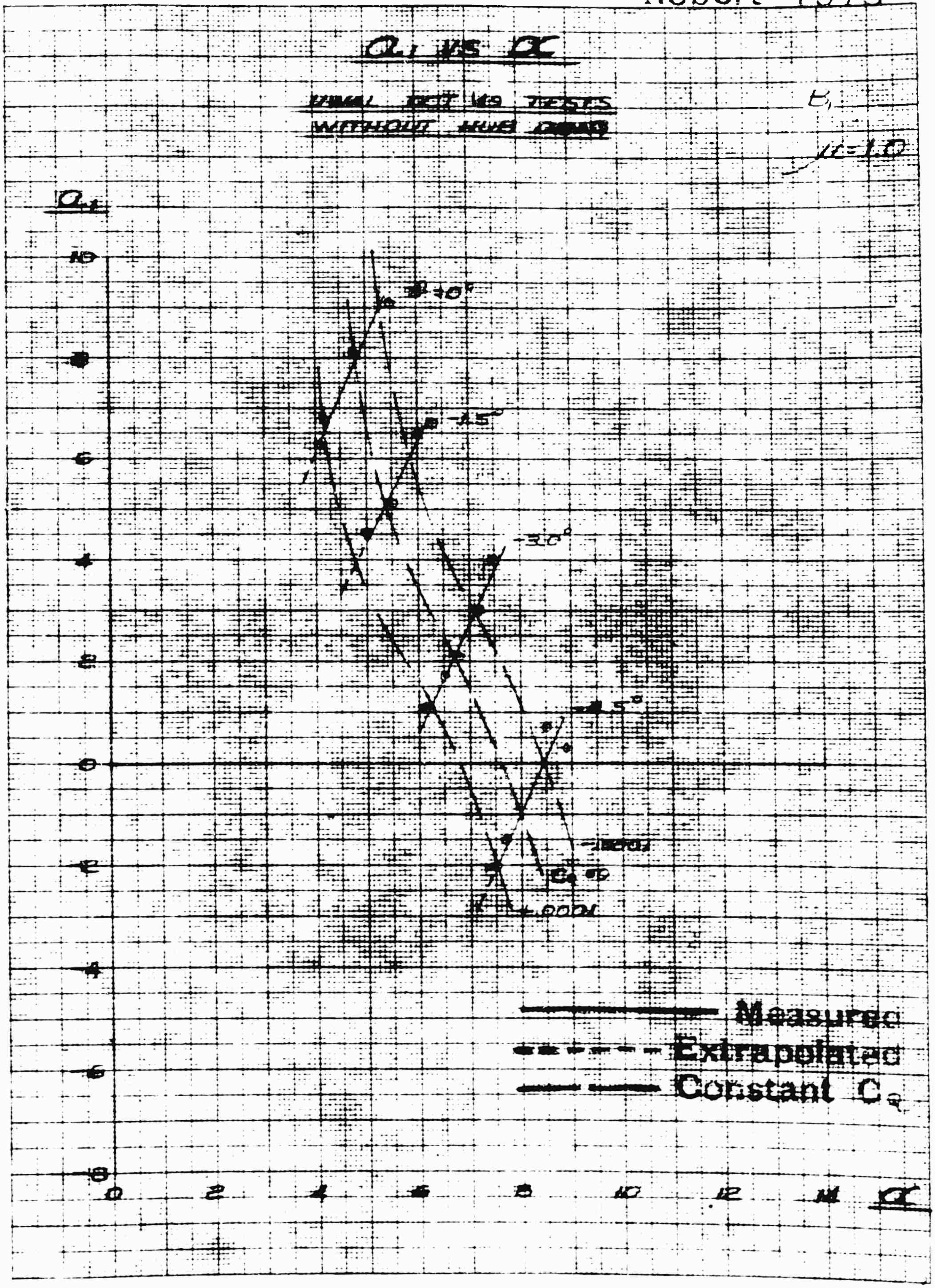
CONFIDENTIAL



KEUFFEL & ESSER CO.



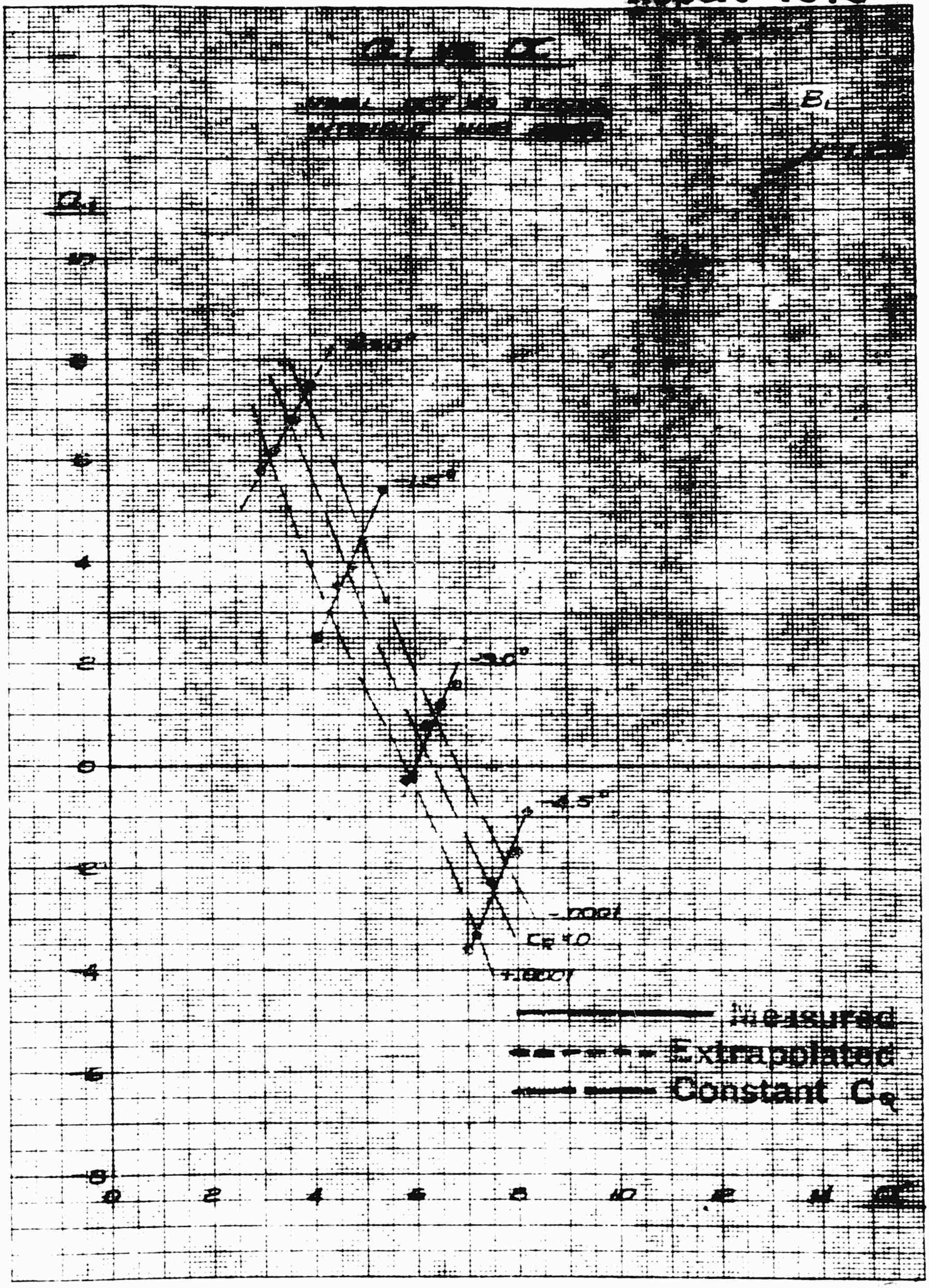
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



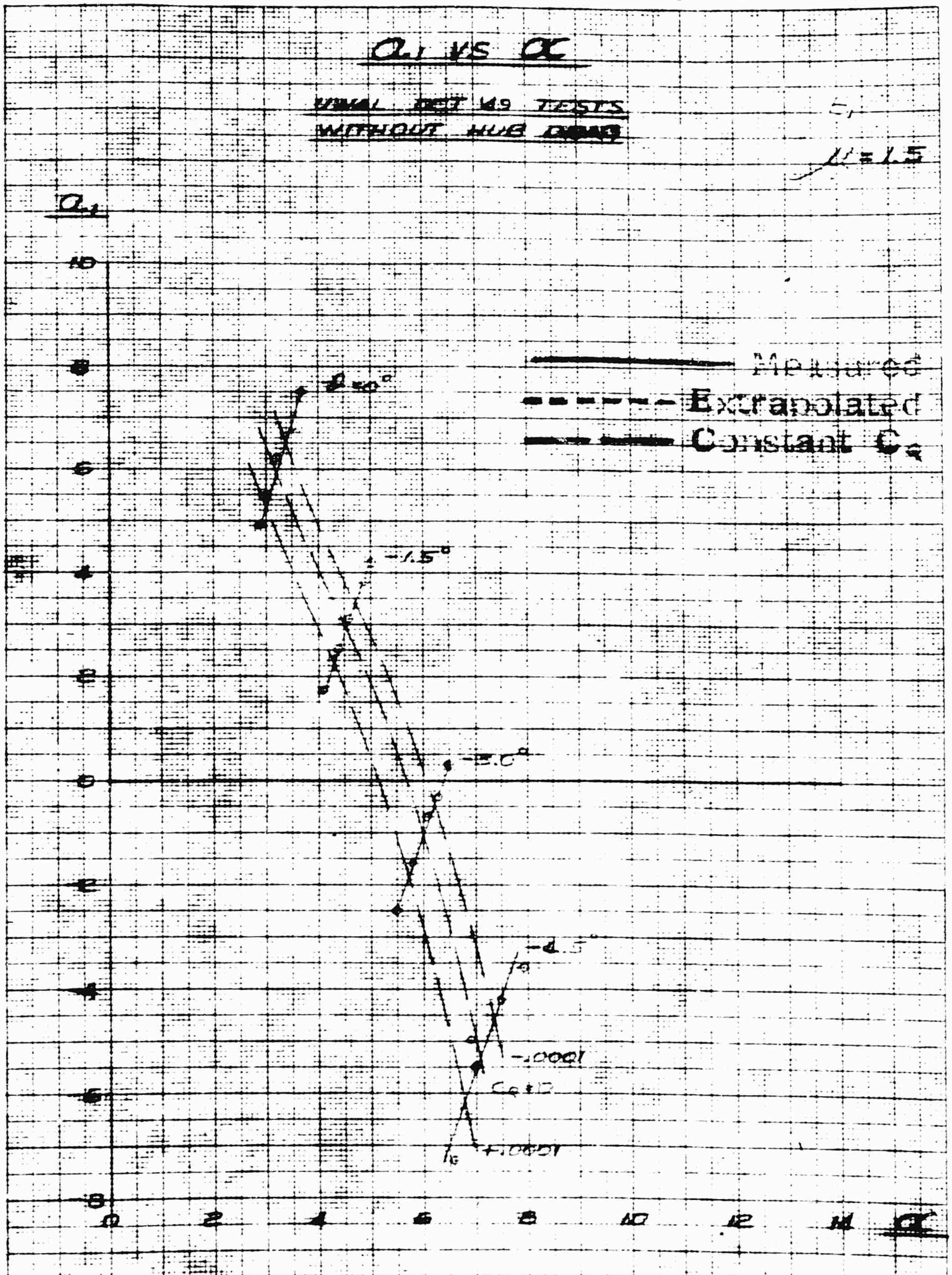
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

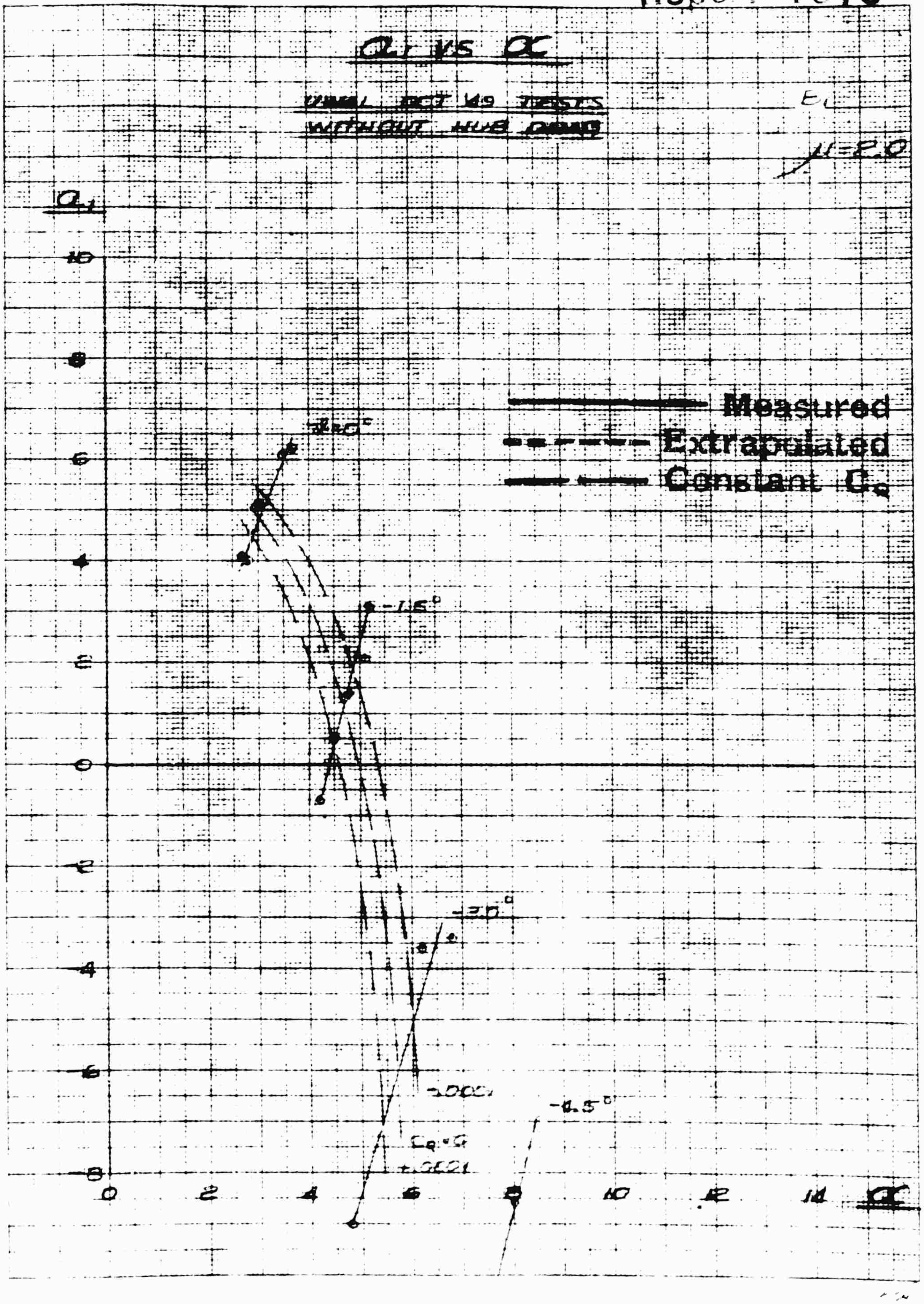
Report 1975



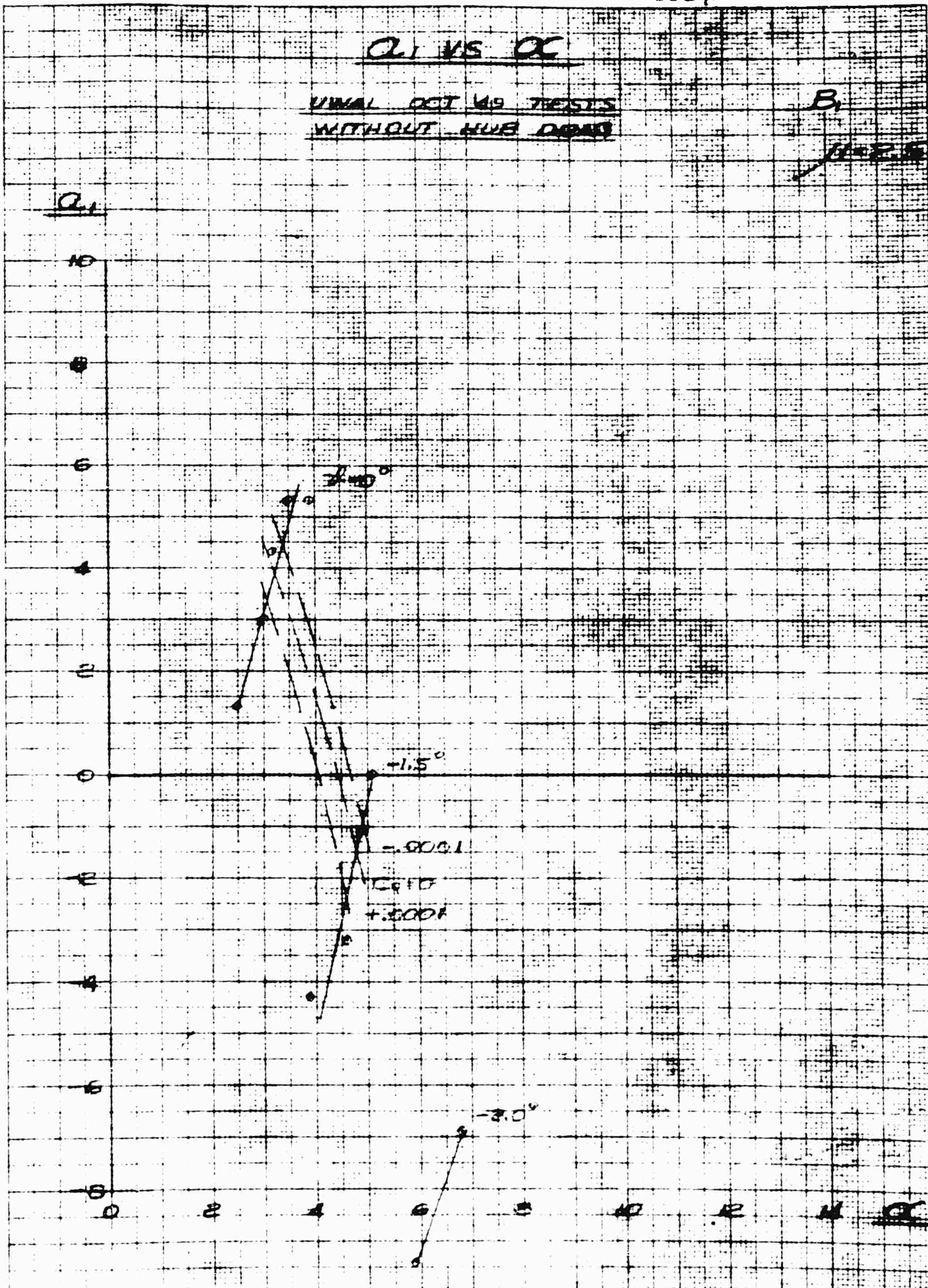
KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented

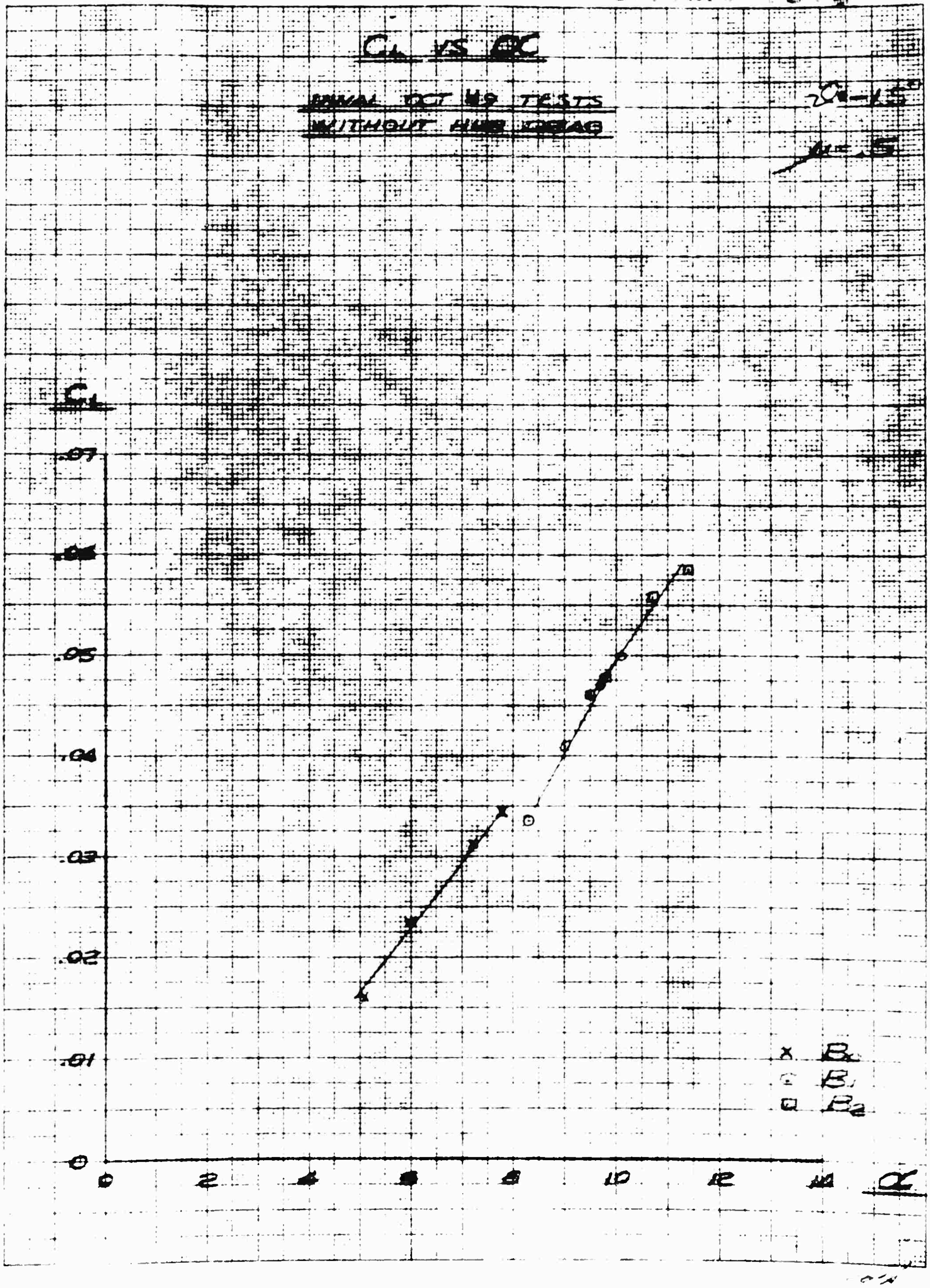


KEUFFEL & ESSER CO.



KEUFFEL & ESSER CO.

Report 1816

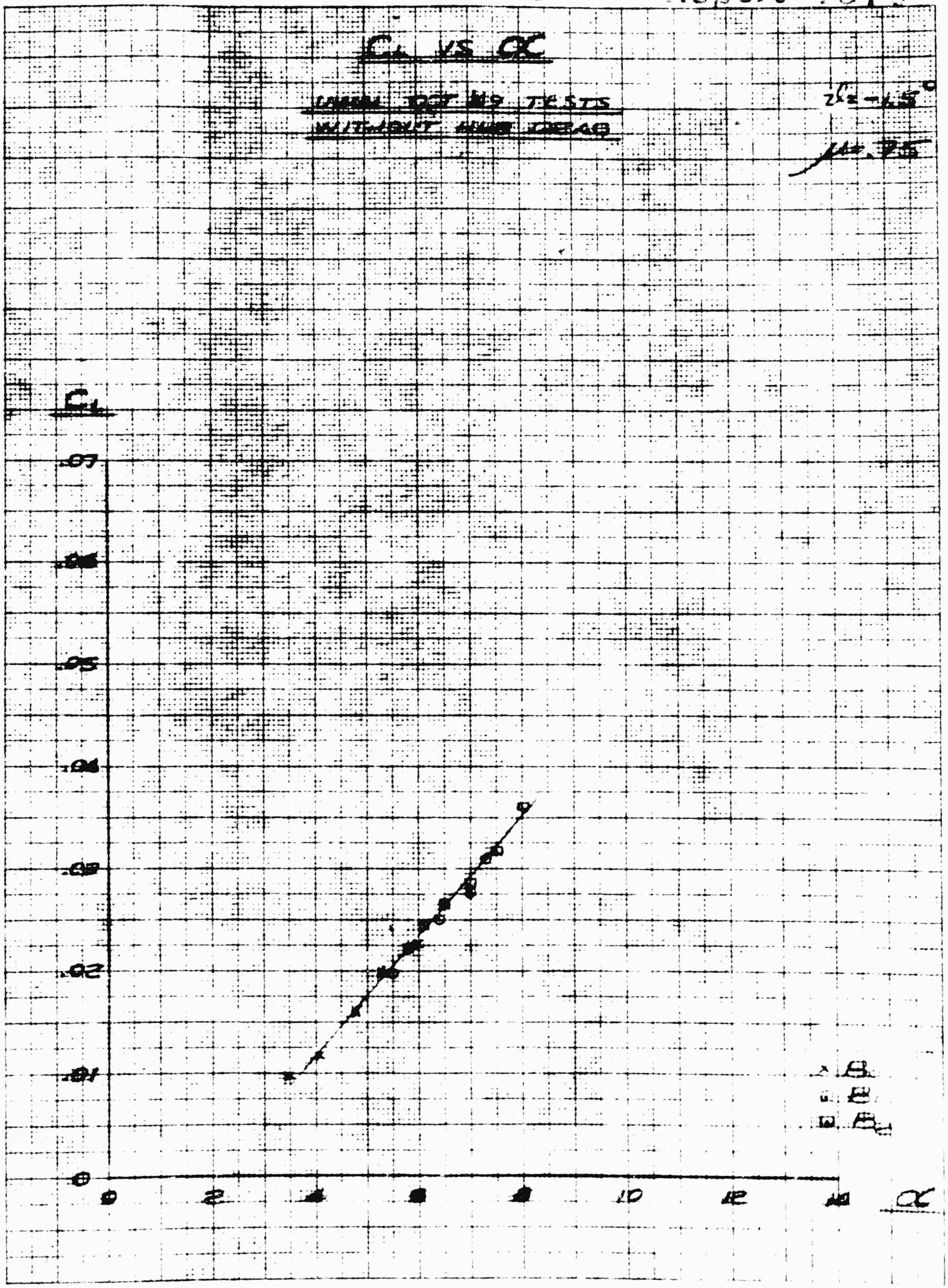


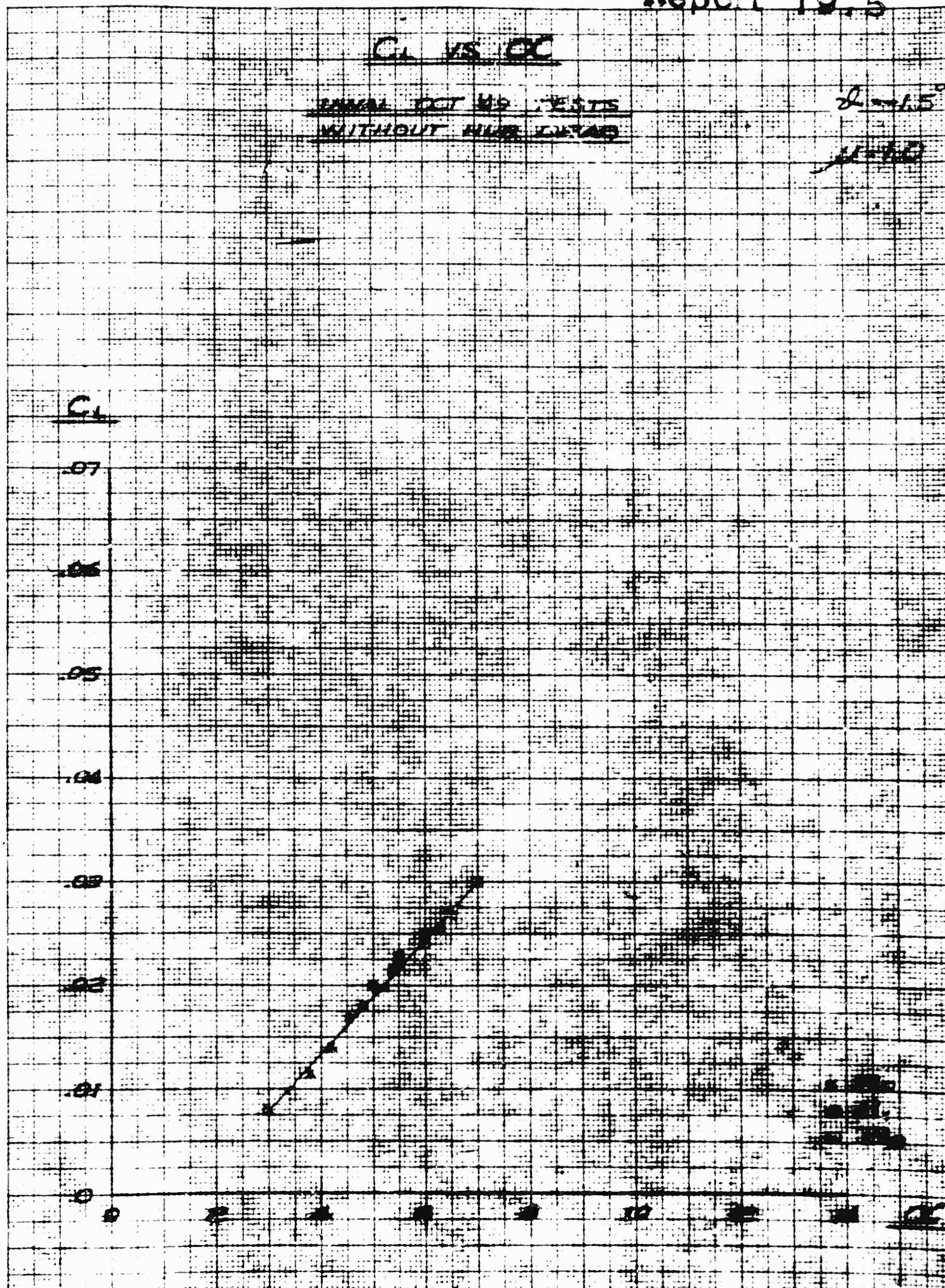
C_L vs α
OCT '49 TESTS
WITHOUT HUB DRAG
$\mu = .5$
C_L
.07
.06
.05
.04
.03
.02
.01
0
0
2
4
6
8
10
12
14
α
× B_0
⊙ B_1
□ B_2

318

CONFIDENTIAL

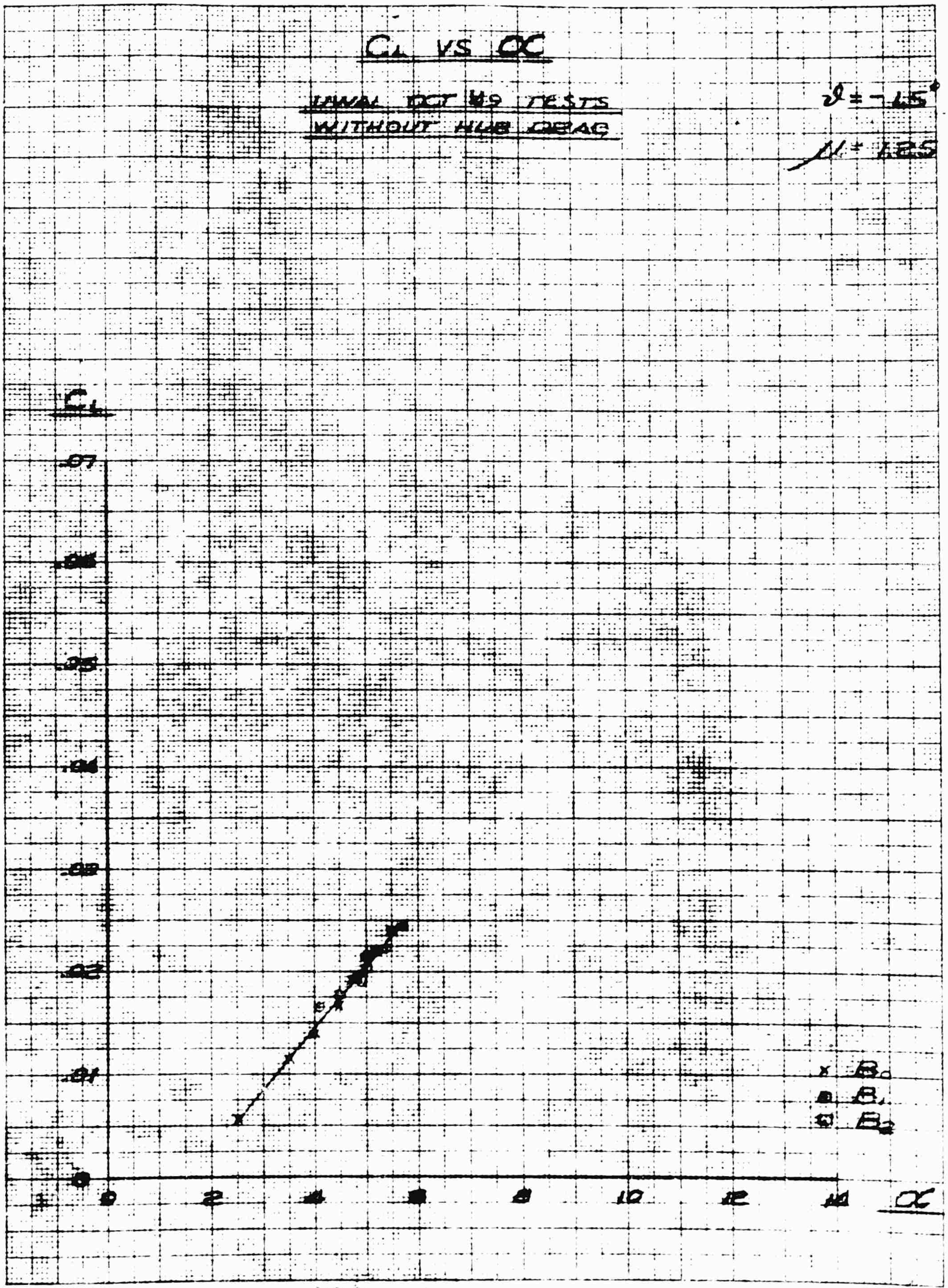
Report 975





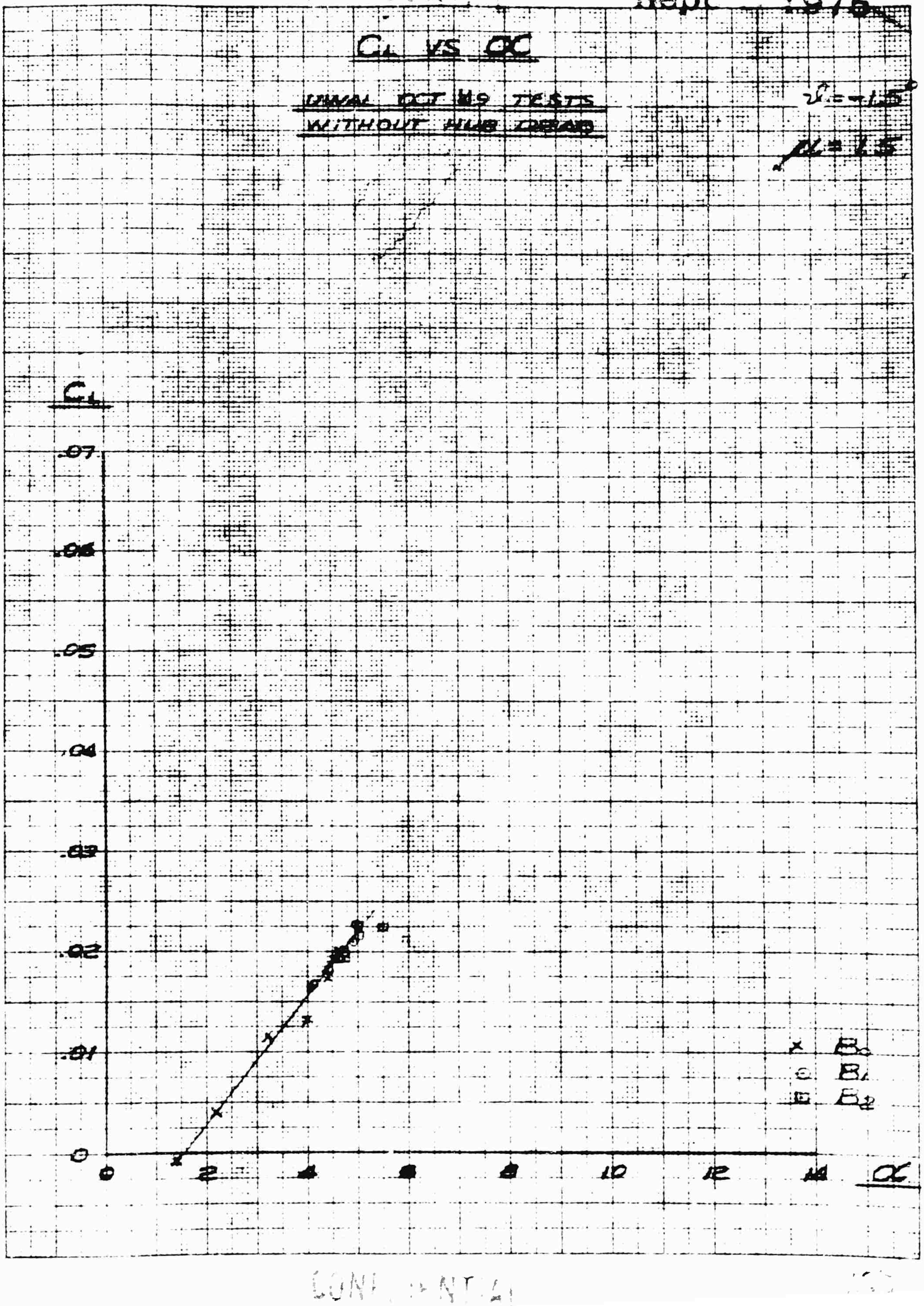
12-13-49

KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

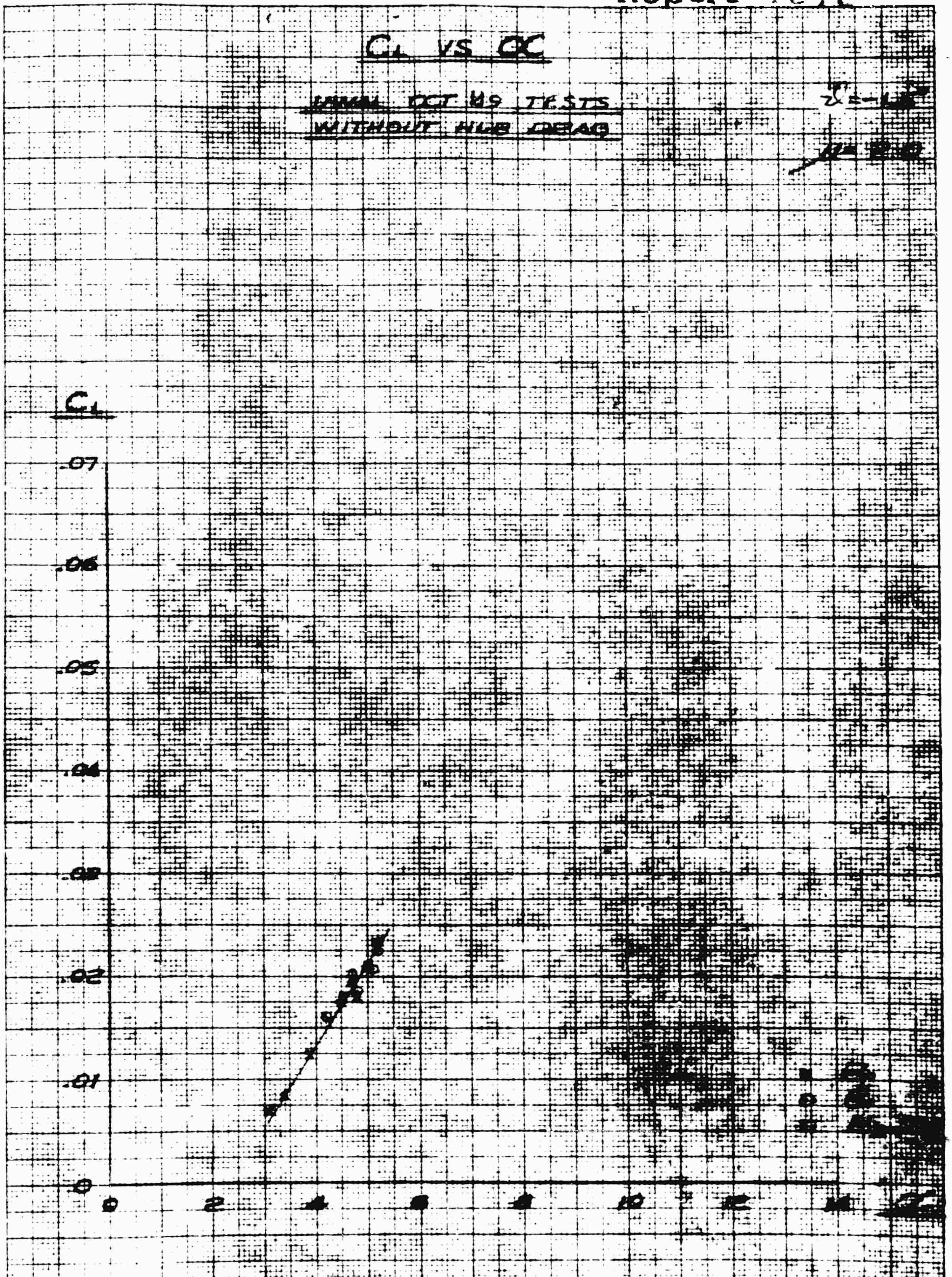
CONFIDENTIAL



KEUFFEL & ESSER CO.

CONFIDENTIAL

CONFIDENTIAL

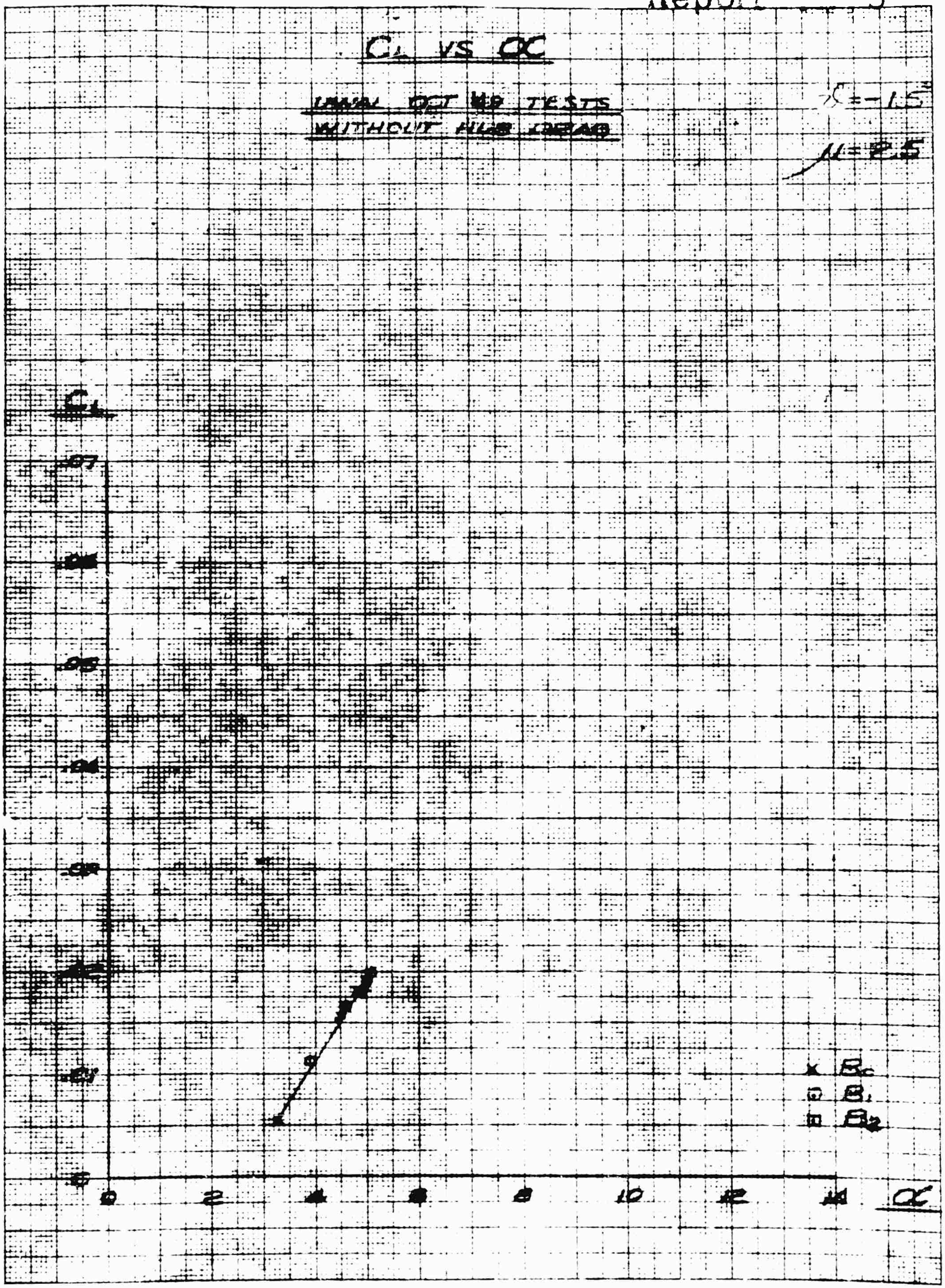


KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

12-13-49

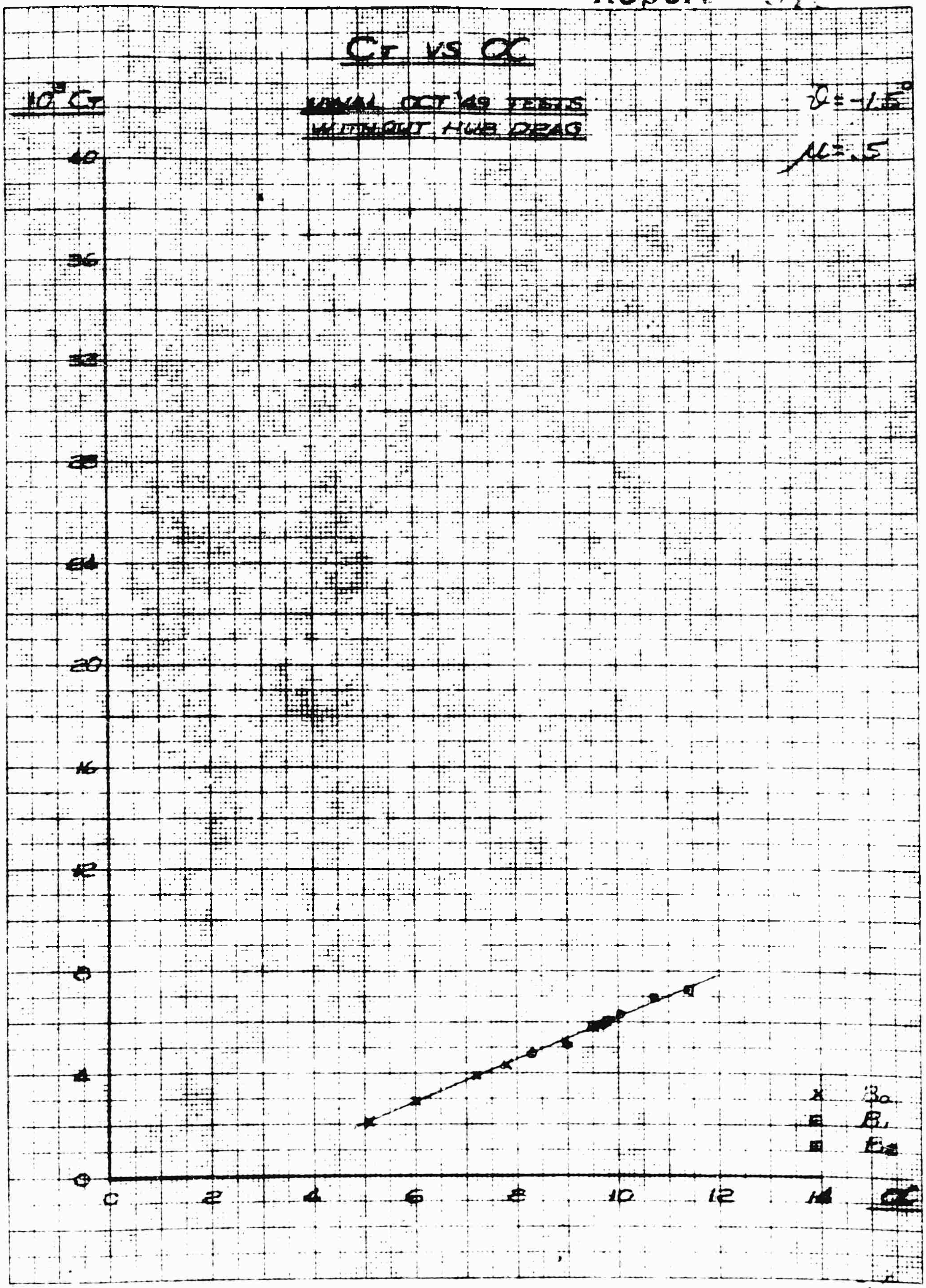
CONFIDENTIAL



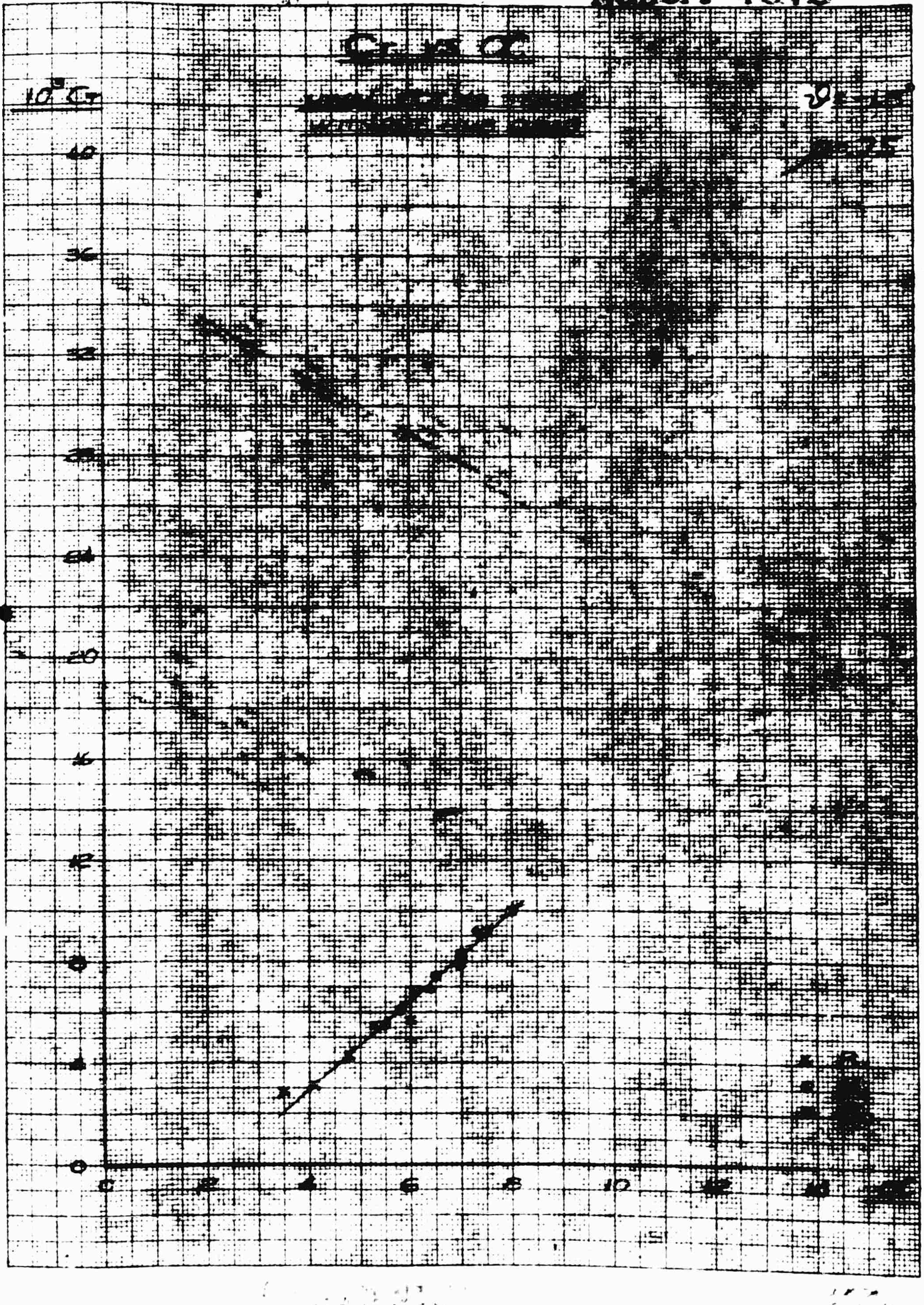
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy.

CONFIDENTIAL

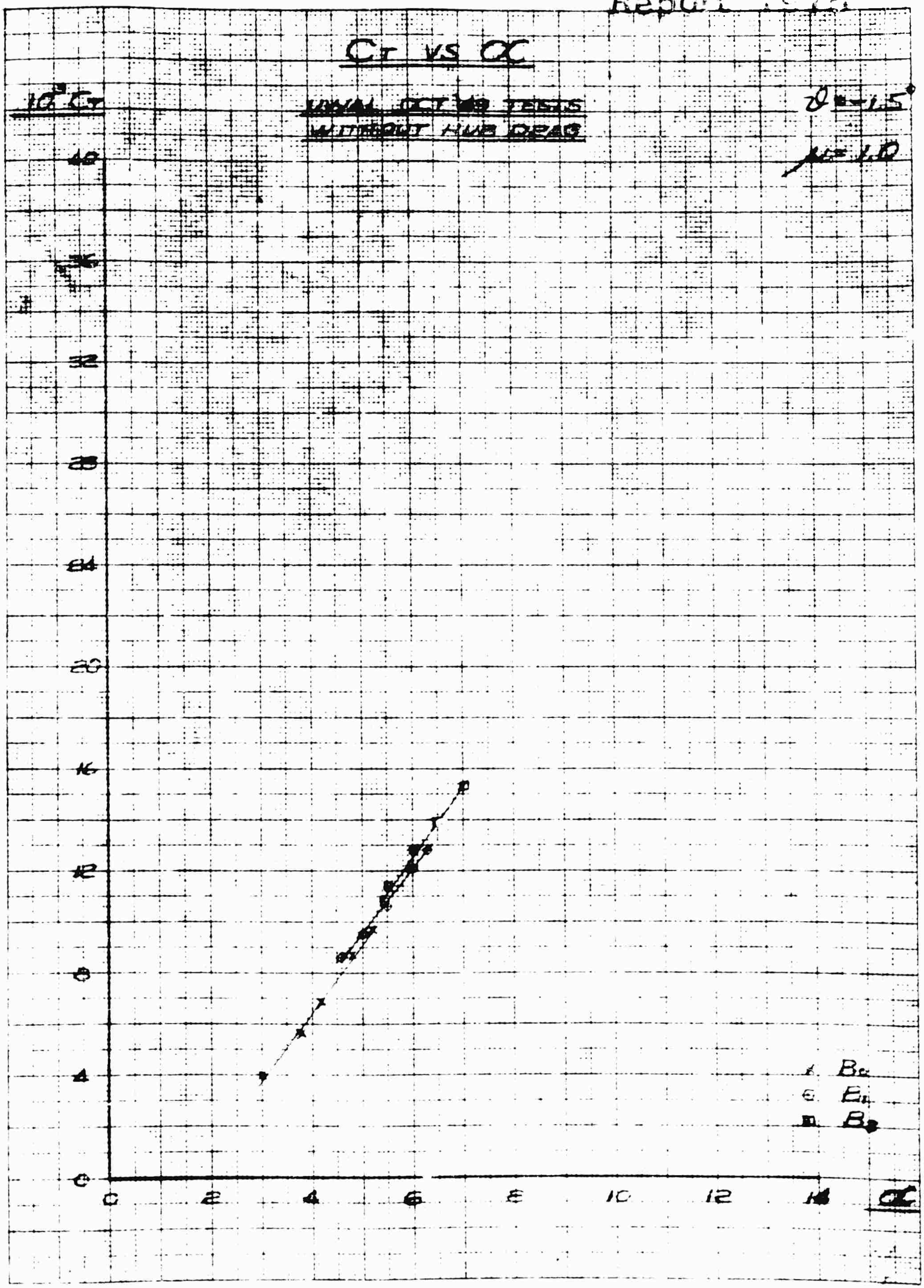
CONFIDENTIAL



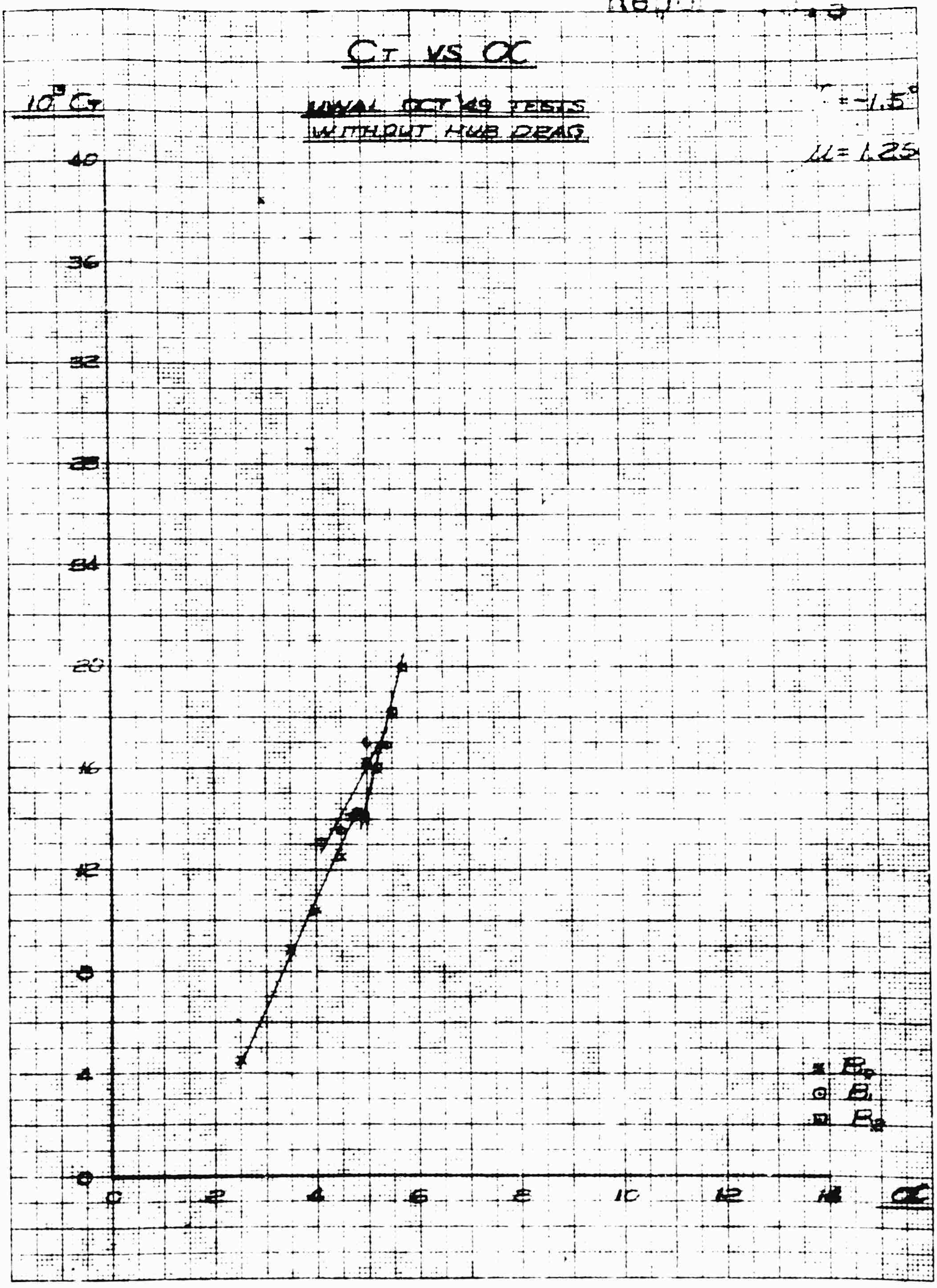
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy



No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy.
KEUFFEL & ESSER CO.



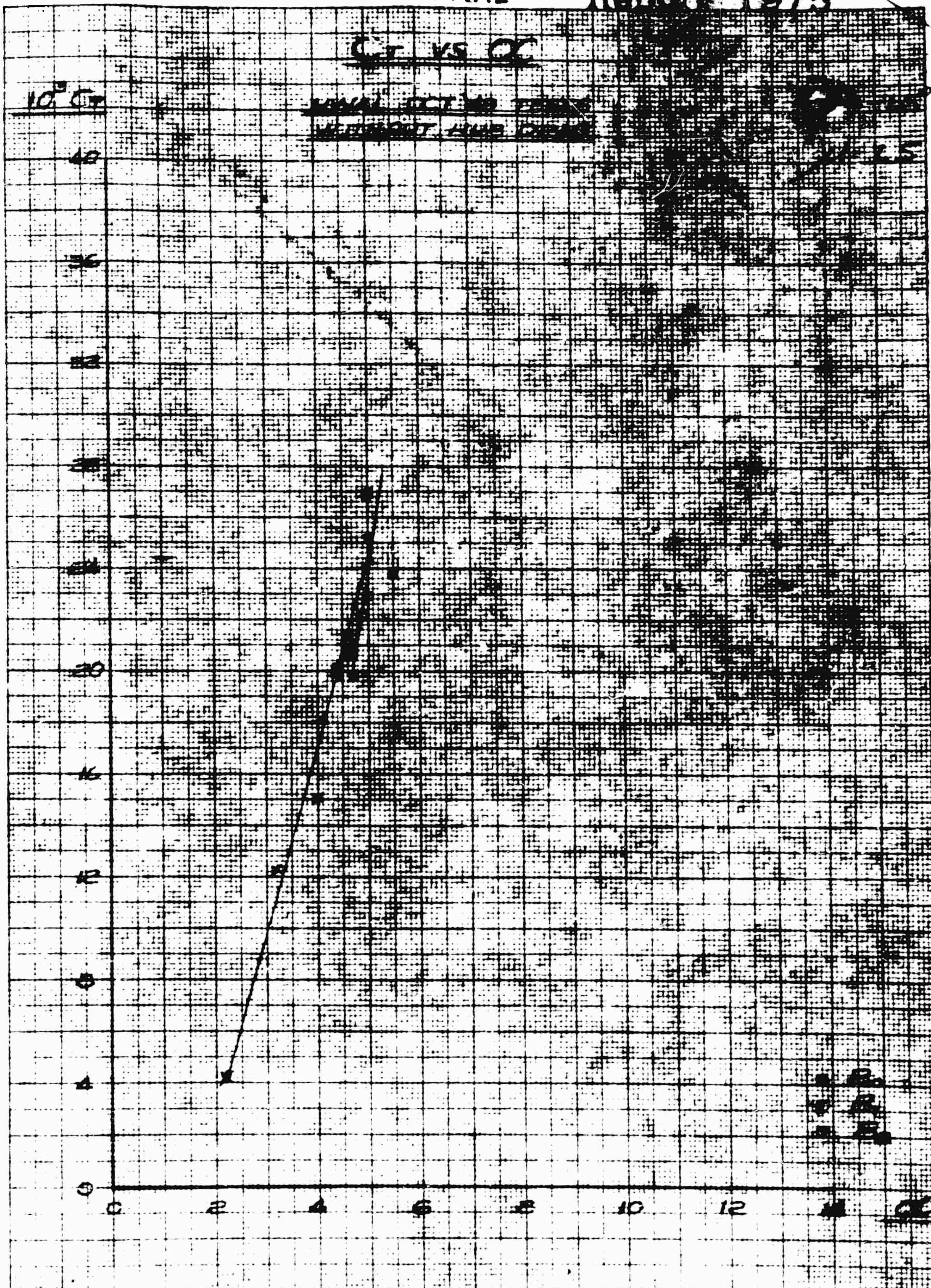
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

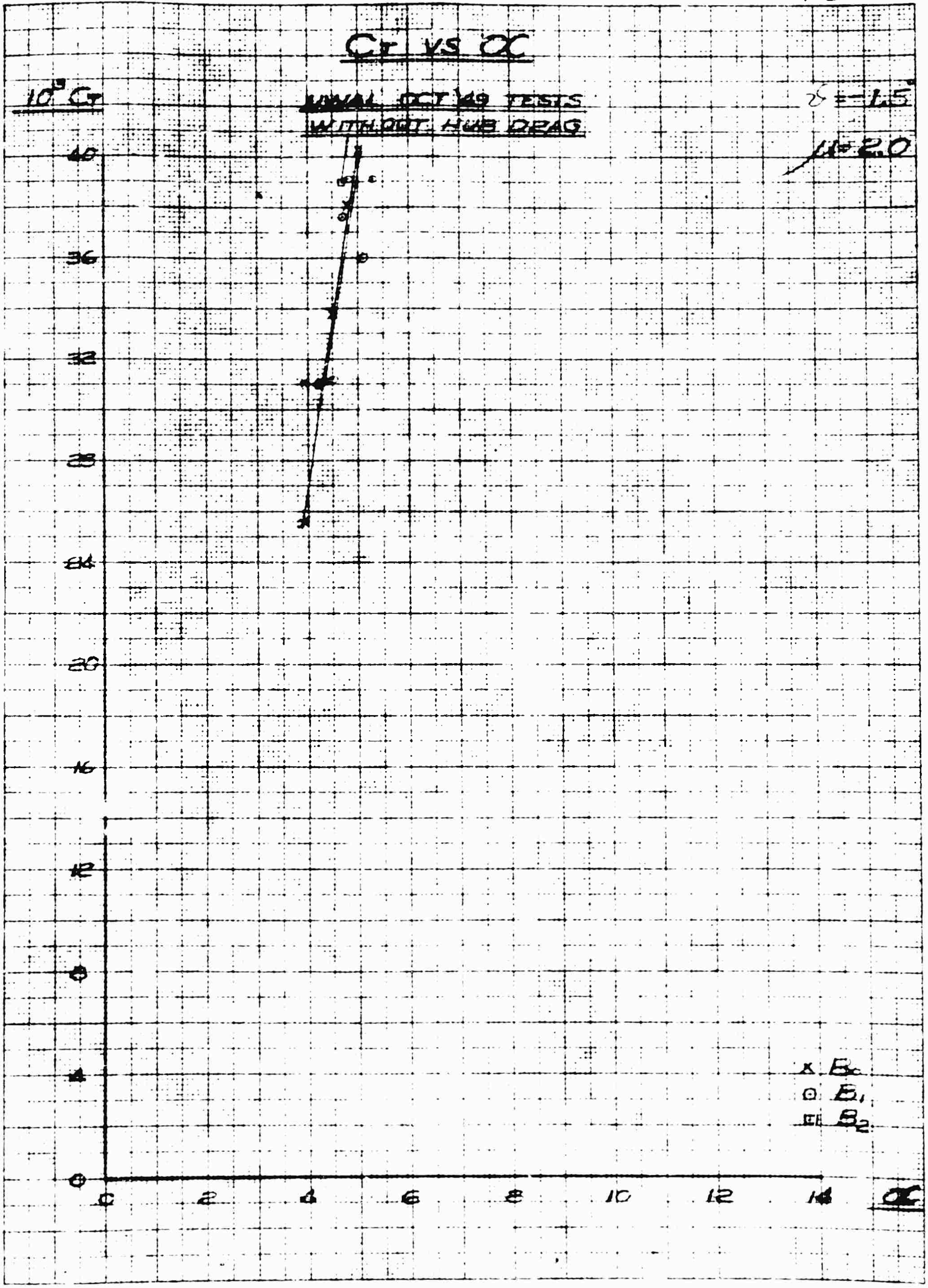
CONFIDENTIAL



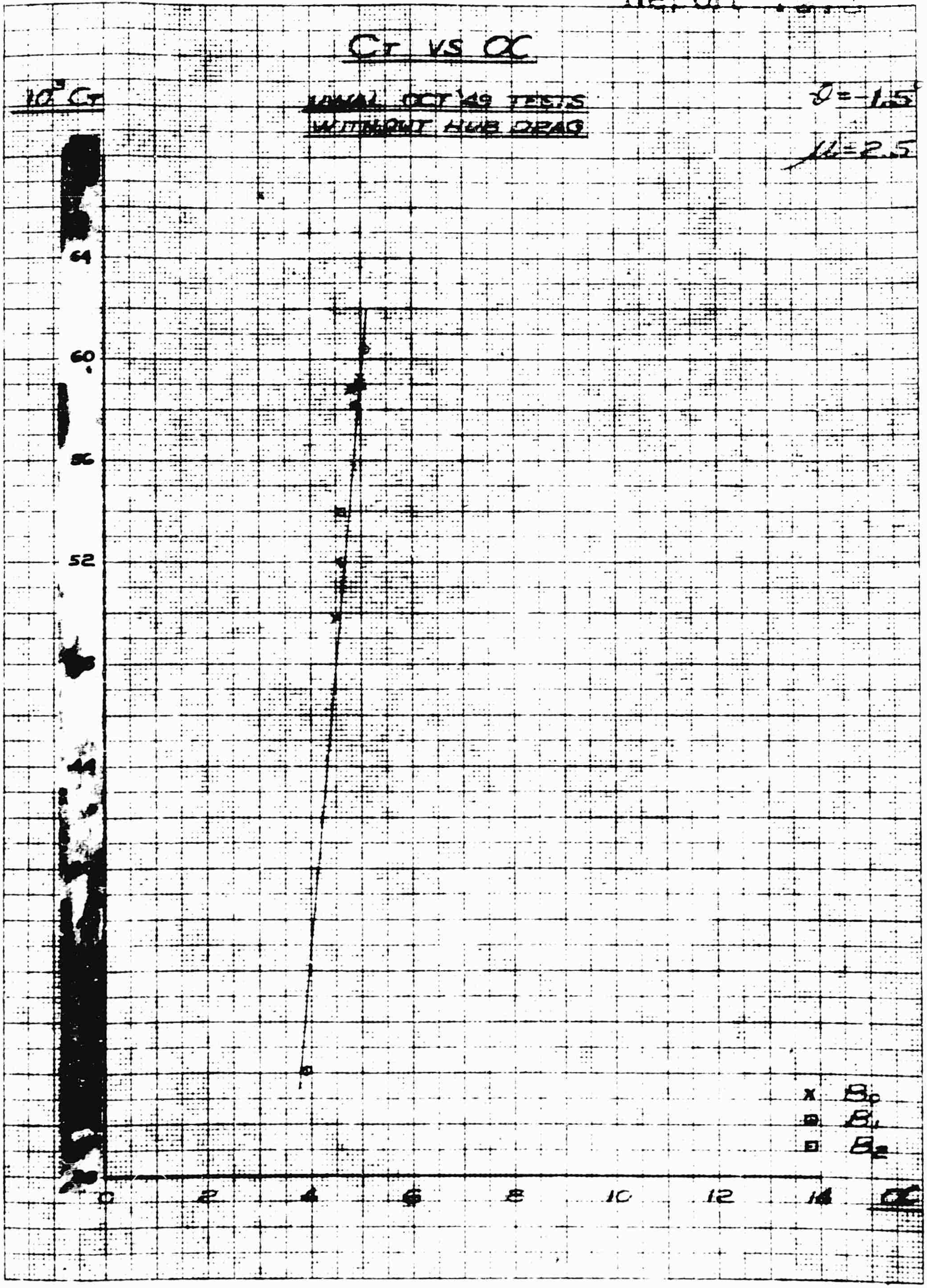
KEUFFEL & ESSER CO.
No. 359-11 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

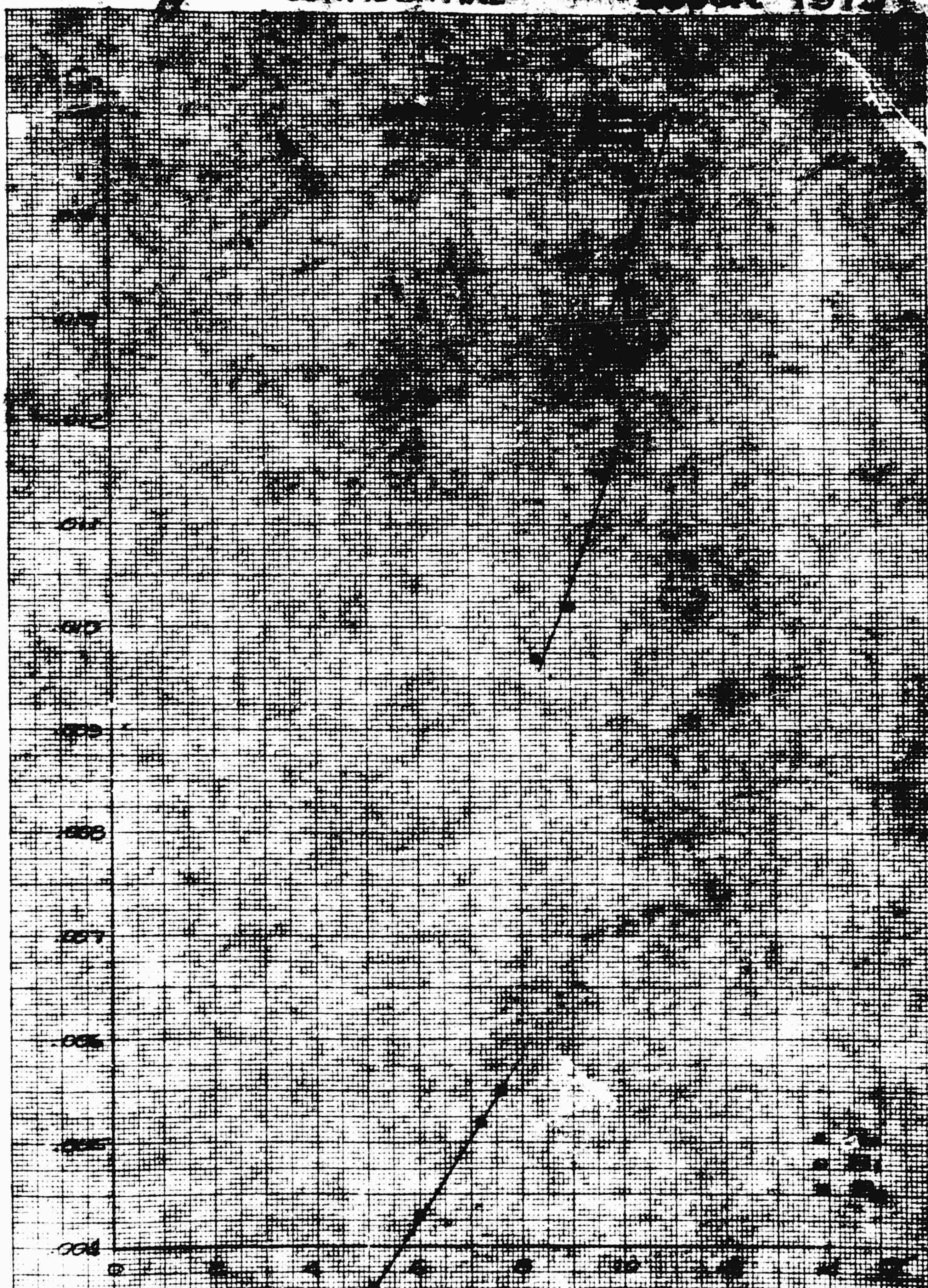
CONFIDENTIAL Report [illegible]75

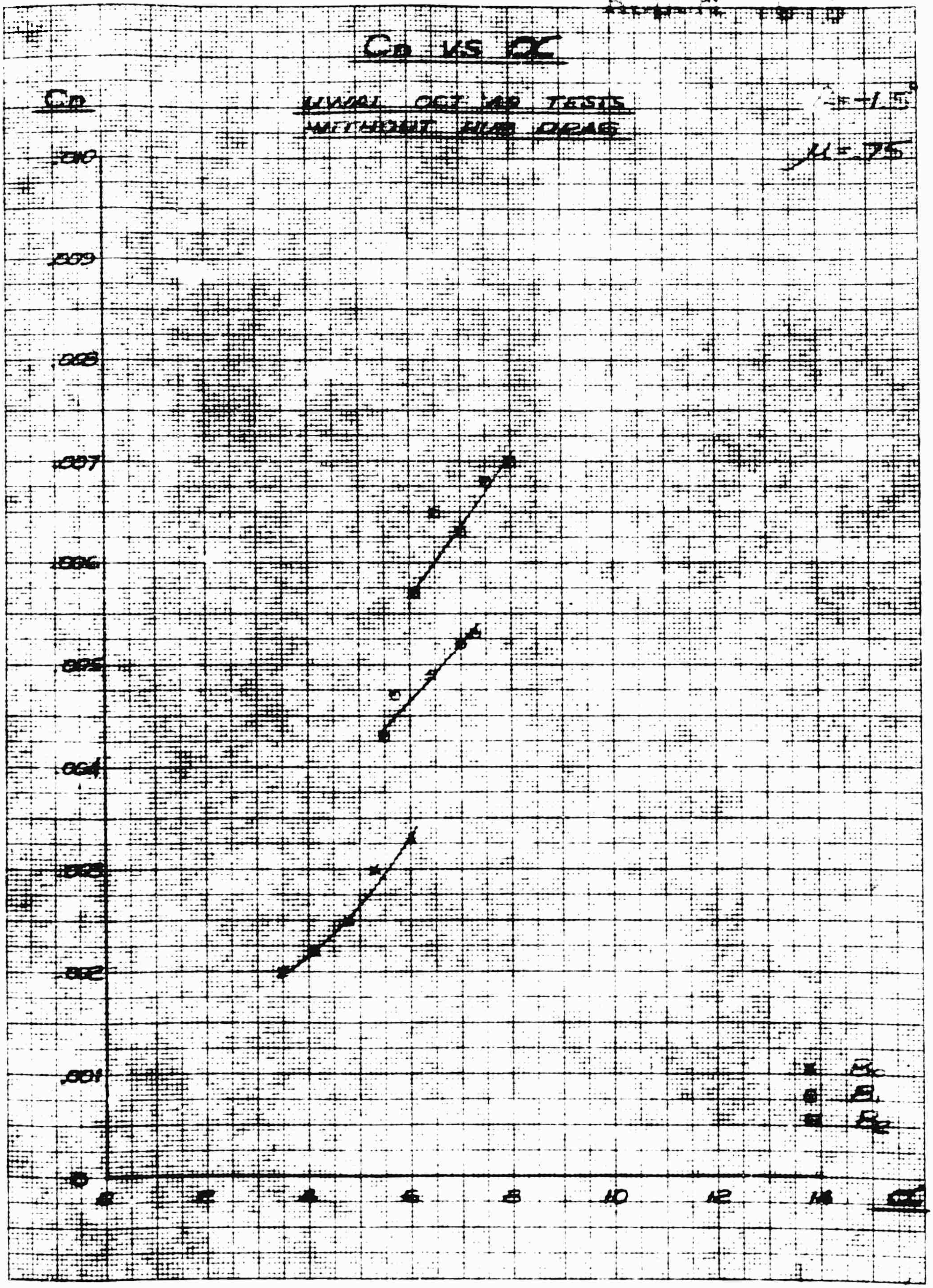


KEUFFEL & ESSER CO.
No. 359 14 Millimeters, 5 mm lines accented, cm lines heavy

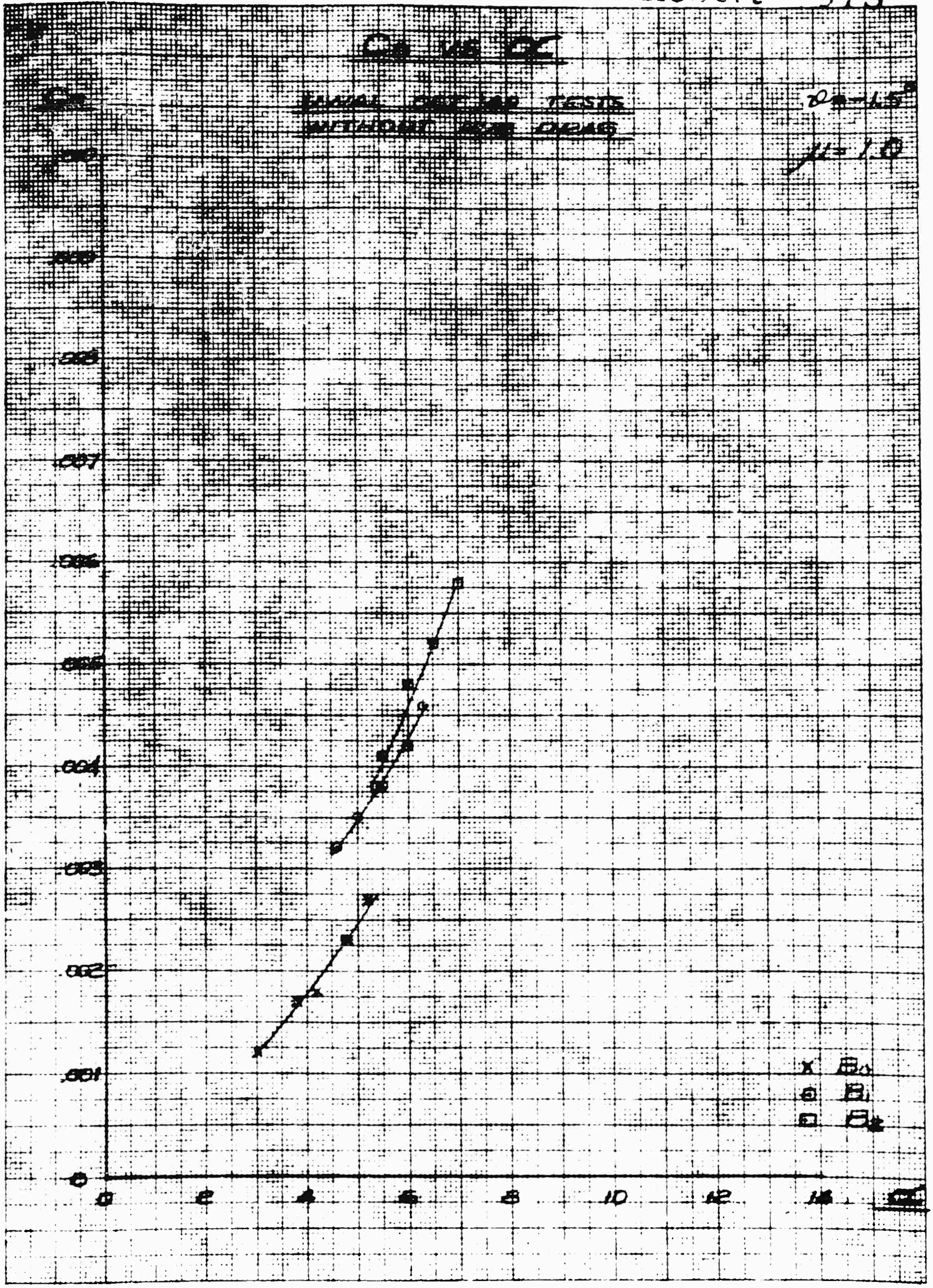


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy





KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

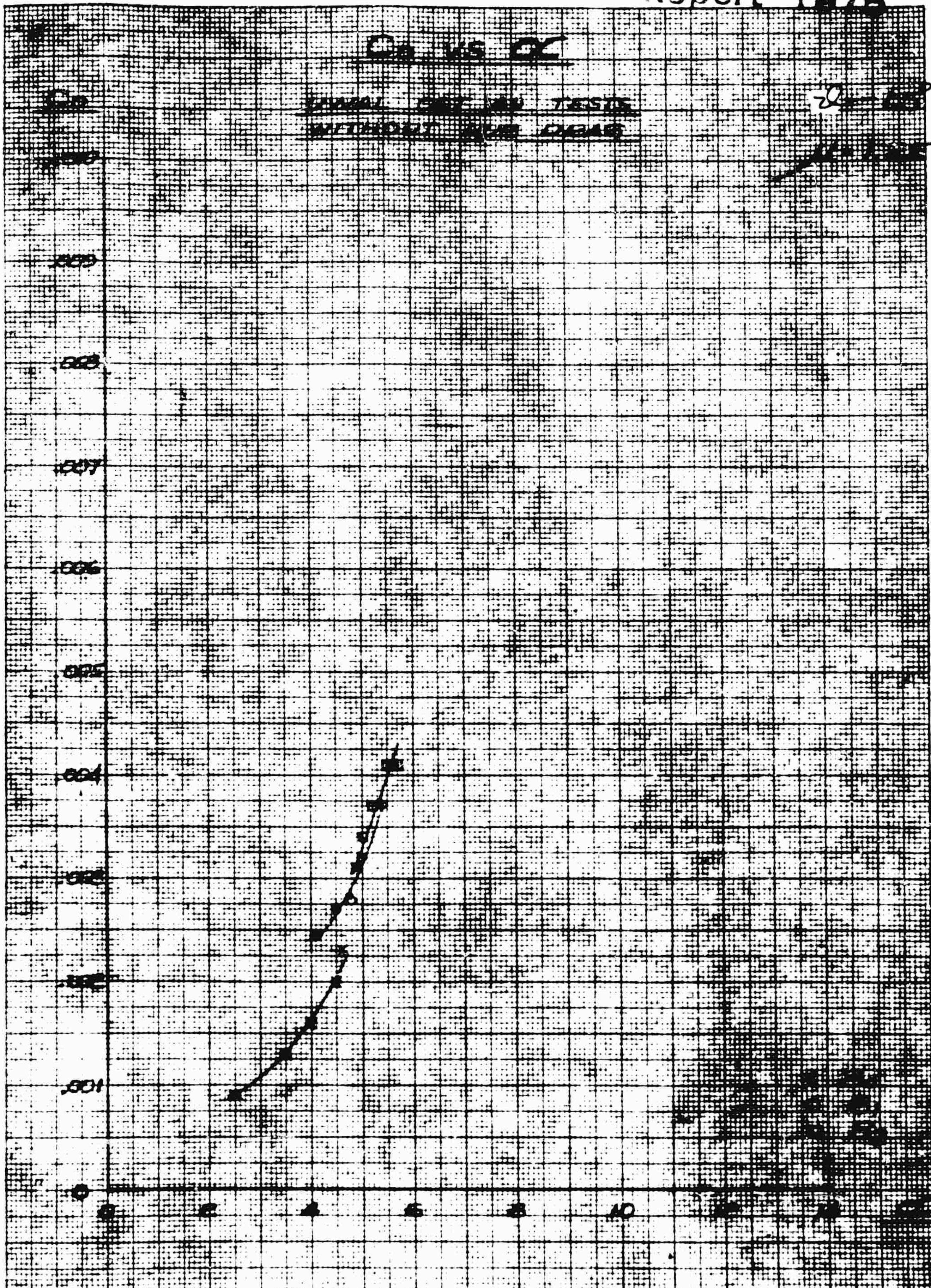


KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

334

Report 1975

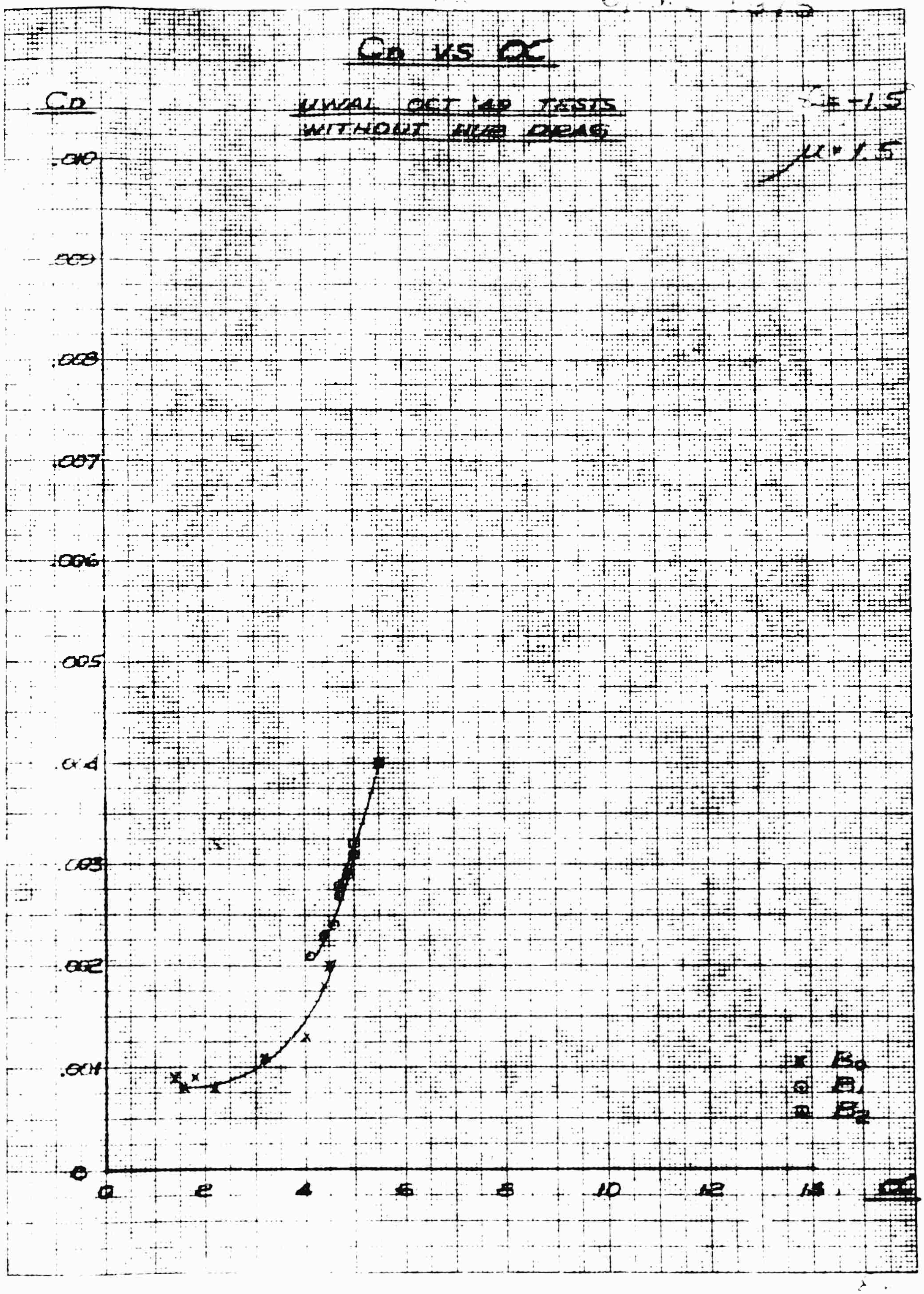


KEUFFEL & ESSER CO.
No 359 14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

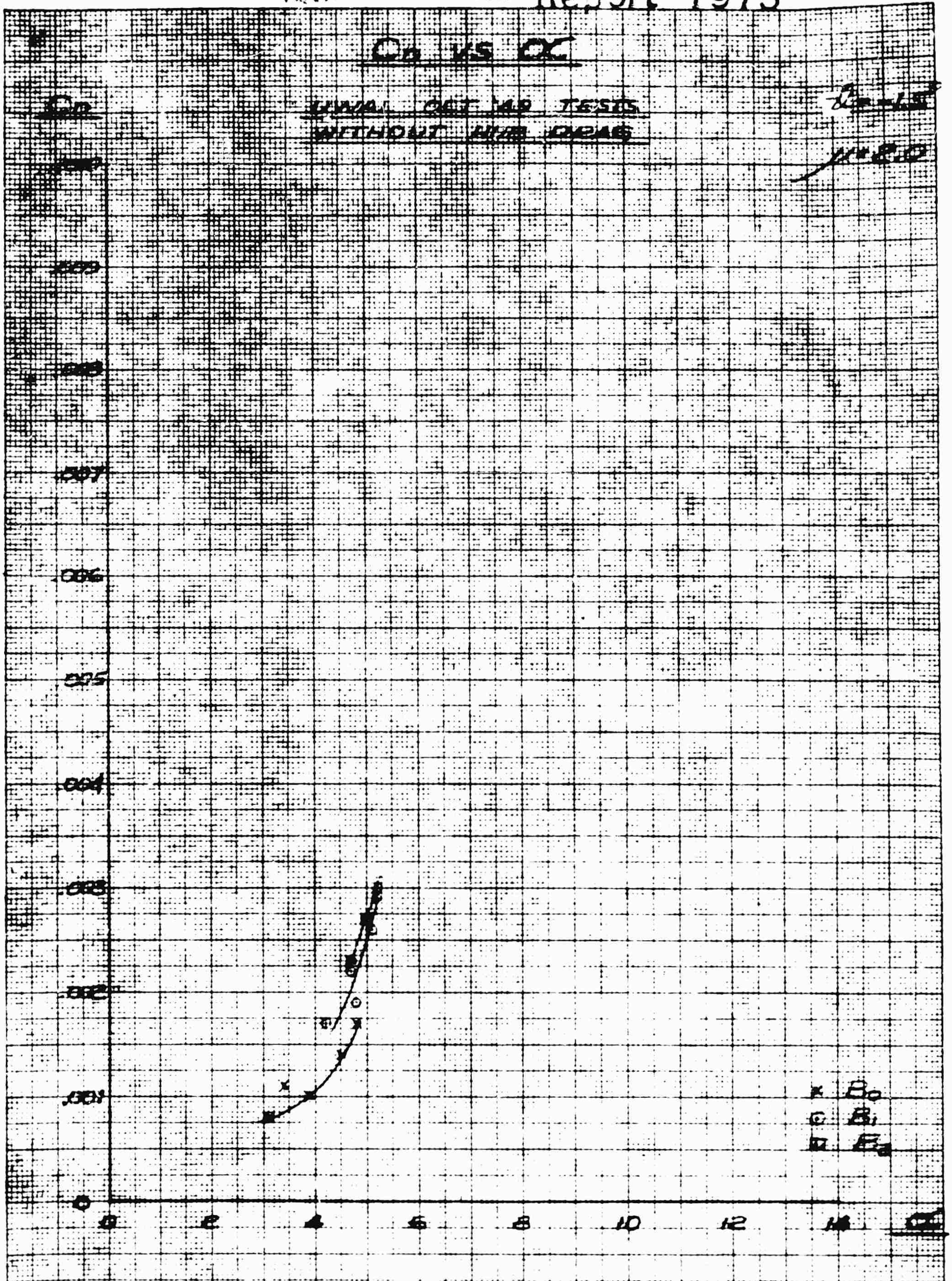
12-13-49

CONFIDENTIAL



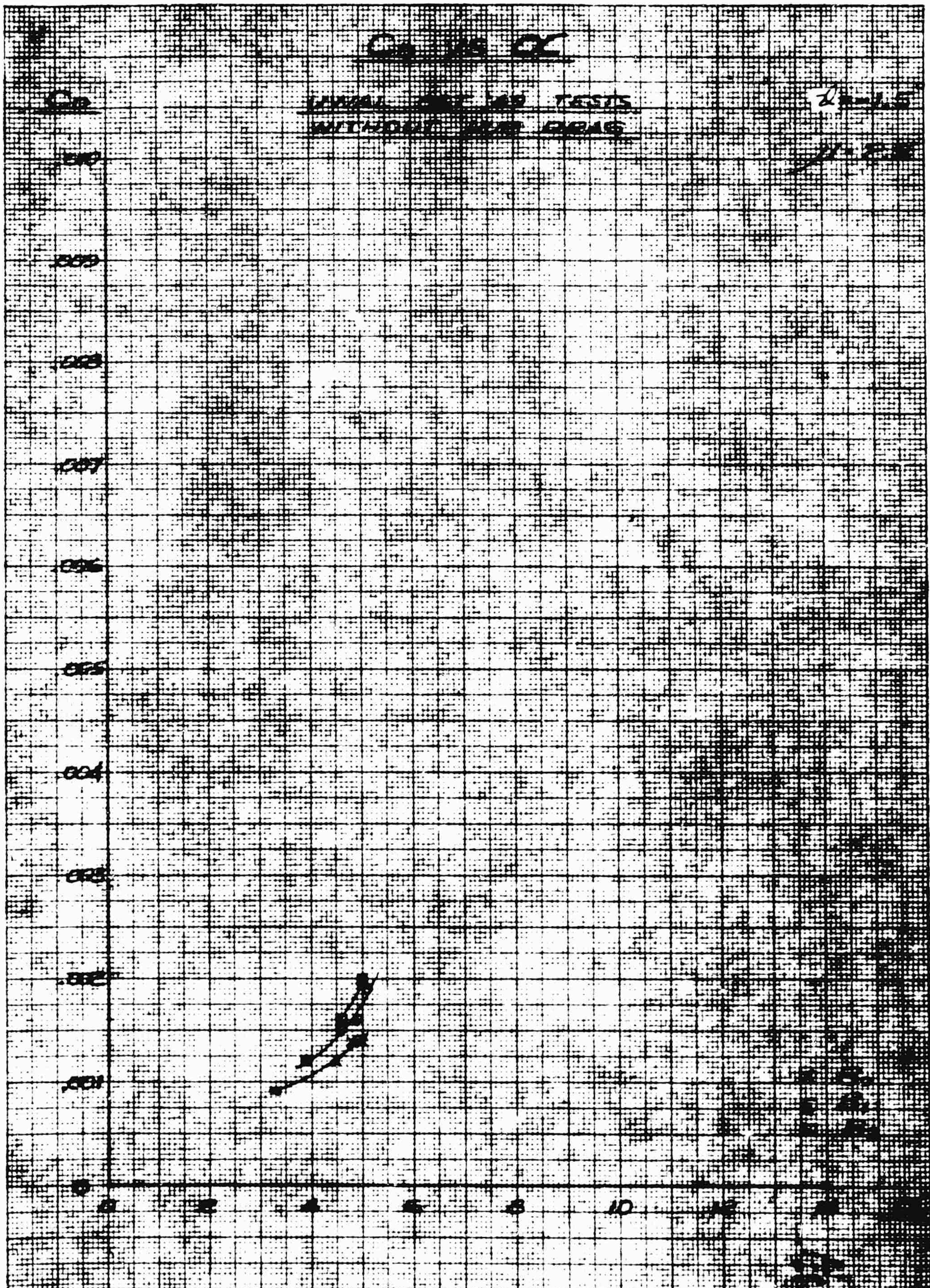
KEUFFEL & ESSER CO.
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL Report 1975



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL Report 1875 337



KEUFFEL & ESSER CO. No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

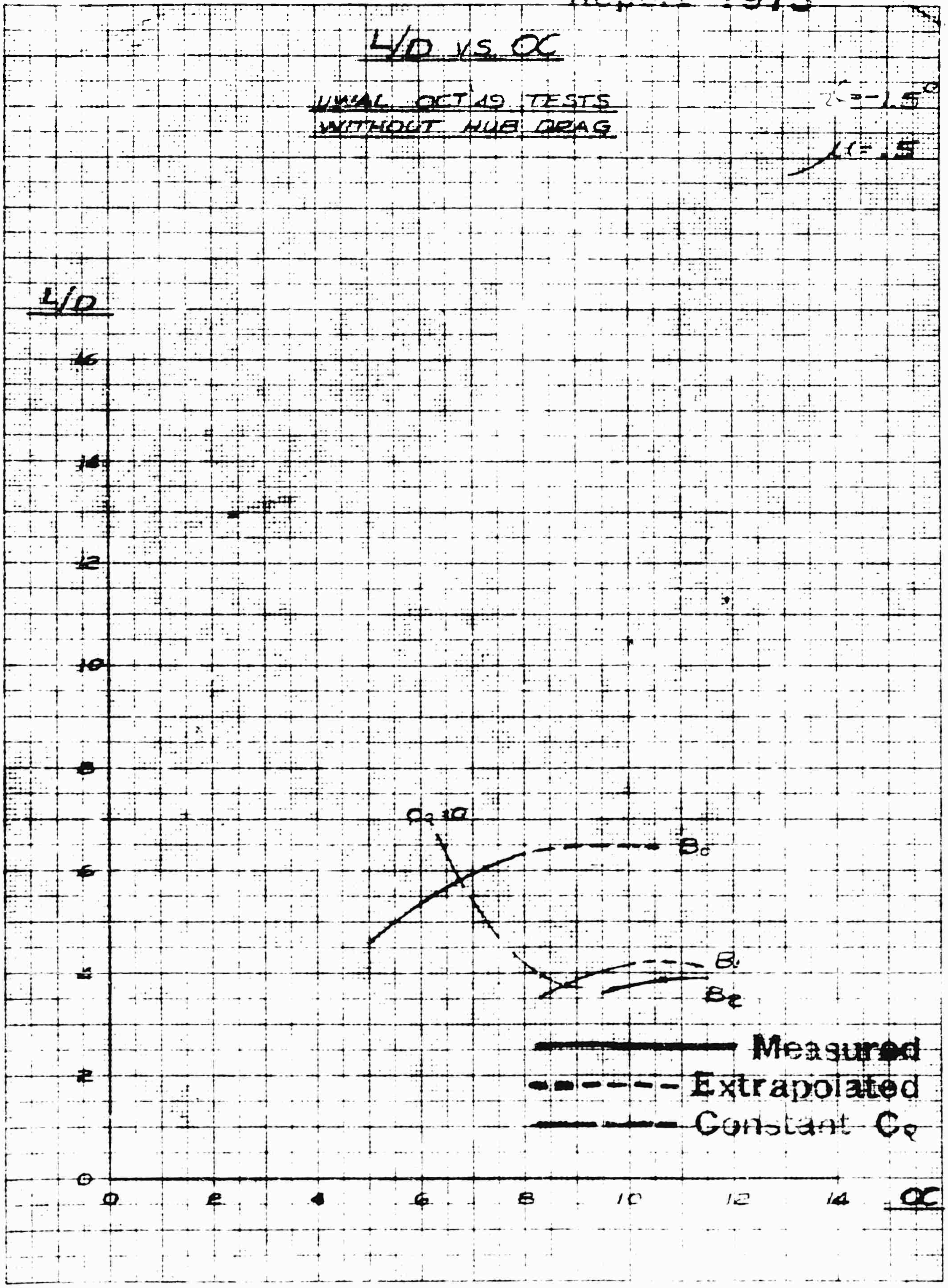
CONFIDENTIAL

12-13-49

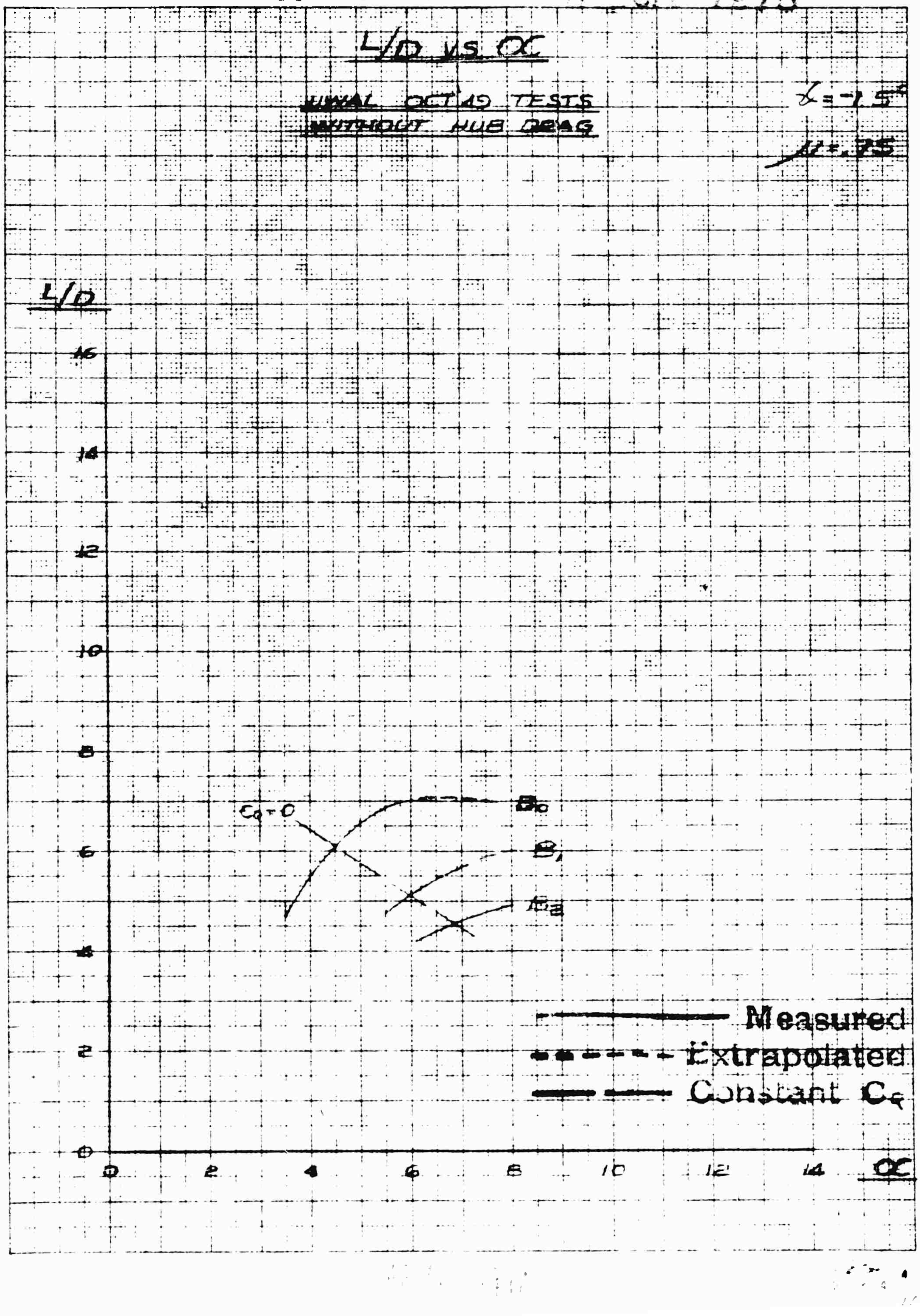
CONFIDENTIAL

338

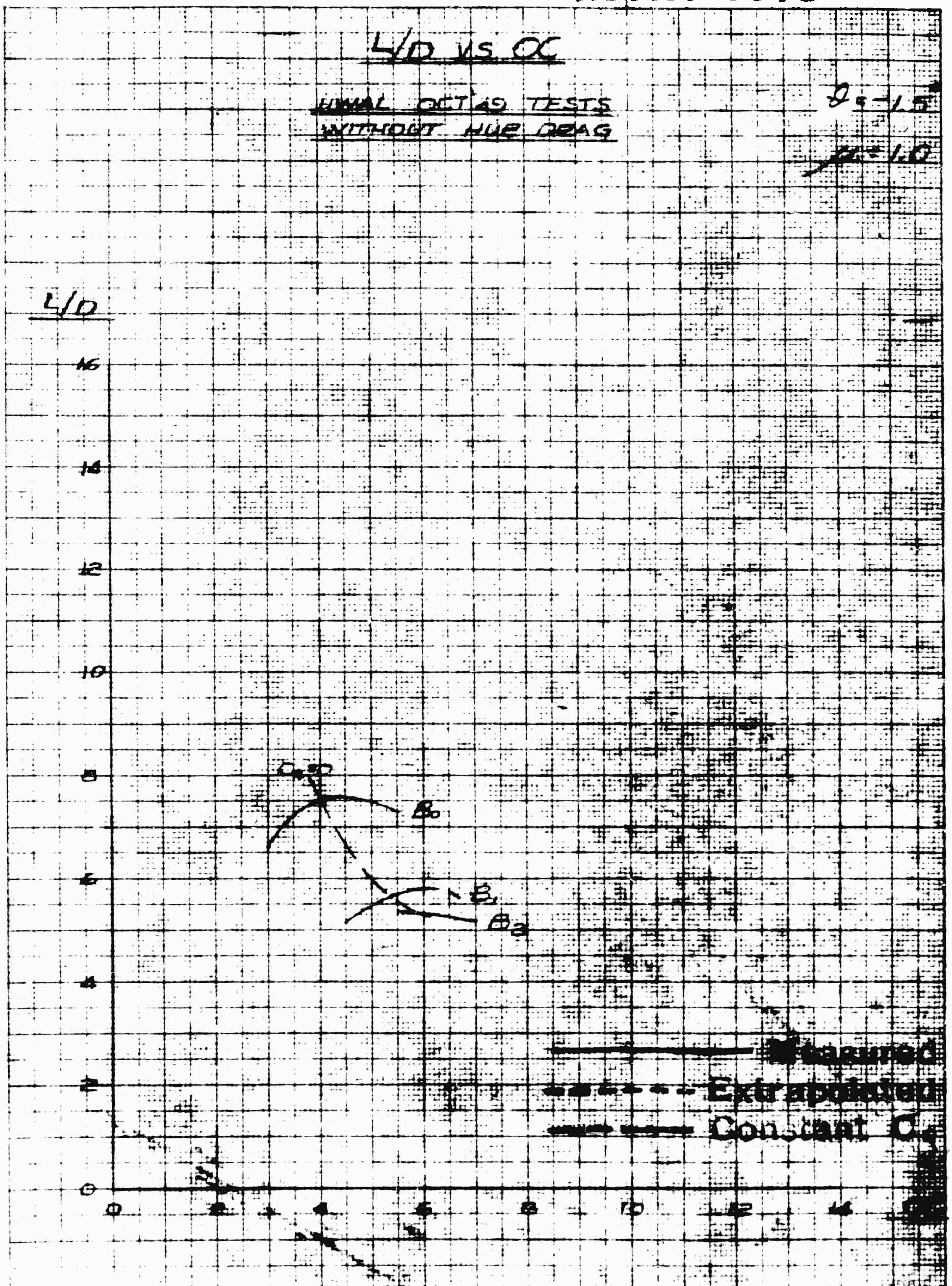
Report 1975



KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, cm lines heavy

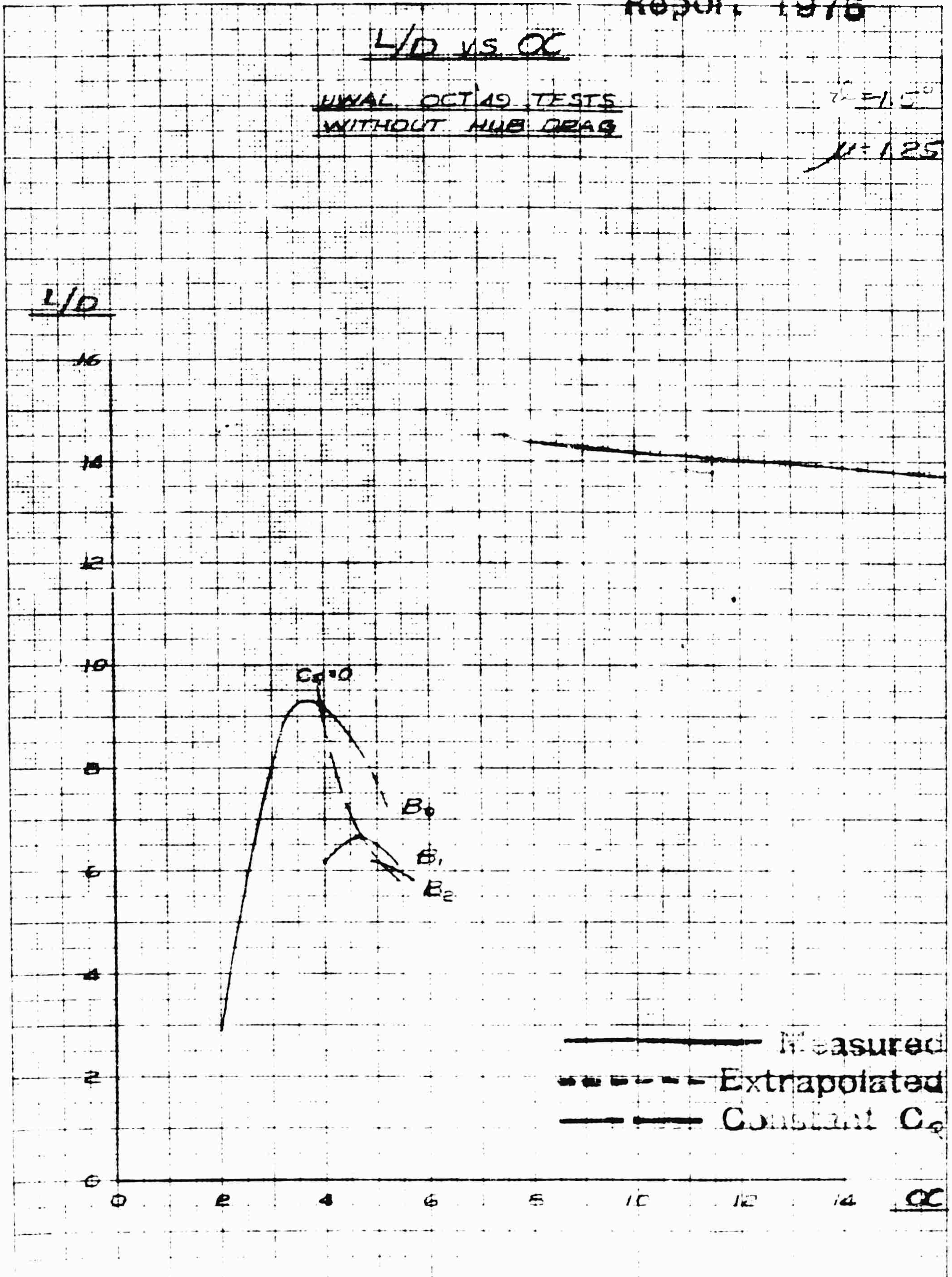


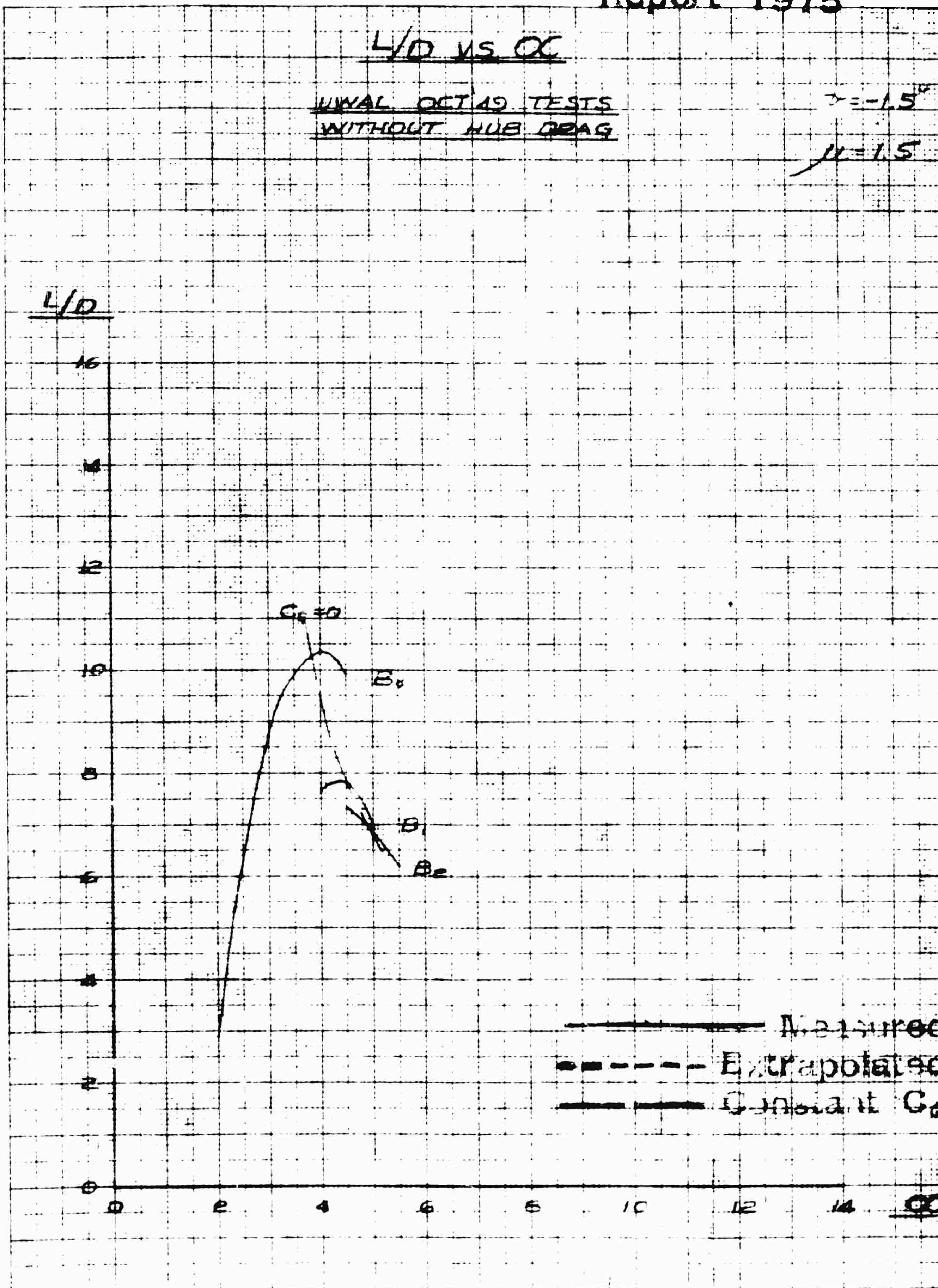
KEUFFEL & ESSER CO.


L/D vs. α
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
θ = 1.5°
μ = 1.0
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
B₀
B₁
B₂
Measured
Extrapolated
Constant

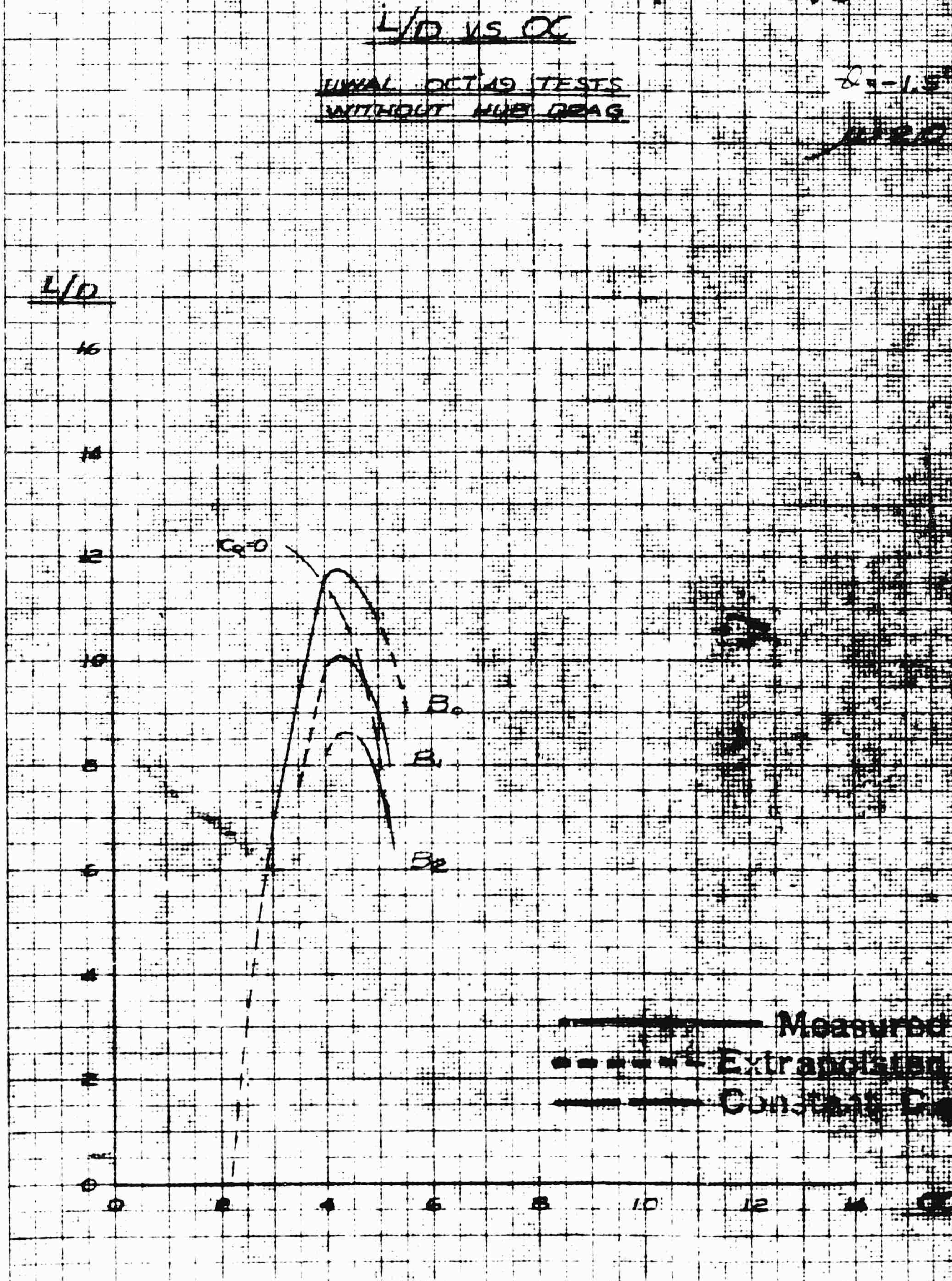
12-13-49

104


L/D vs. OC
UWAL OCT '49 TESTS
WITHOUT HUB DRAG
$\theta = 15°$
$\mu = 1.25$
L/D
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
OC
$C_Q = 0$
B_0
B_1
B_2
Measured
Extrapolated
Constant C_Q



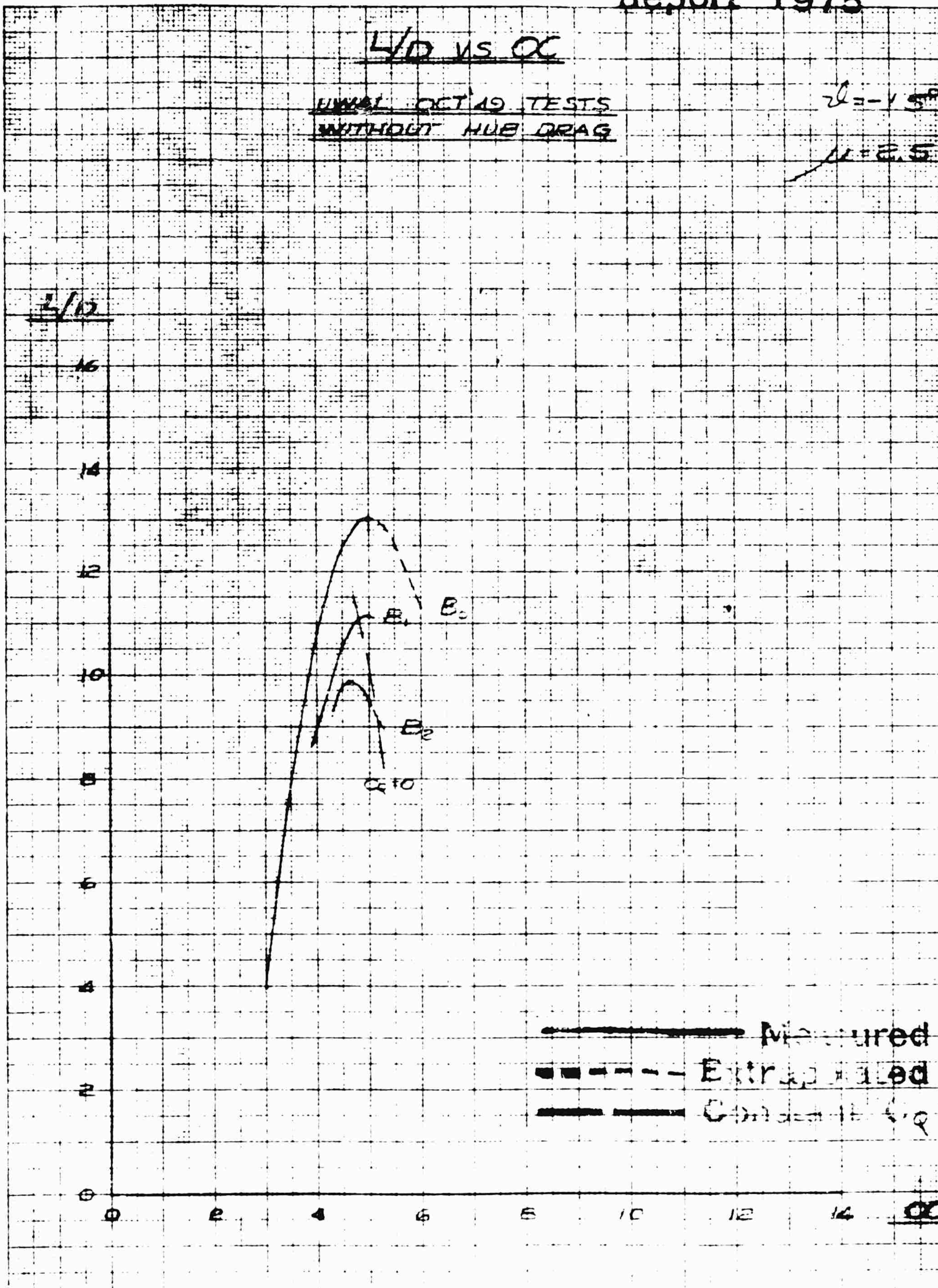
KEUFFEL & ESSER CO.
Millimeters, 5 mm lines accented, cm lines heavy



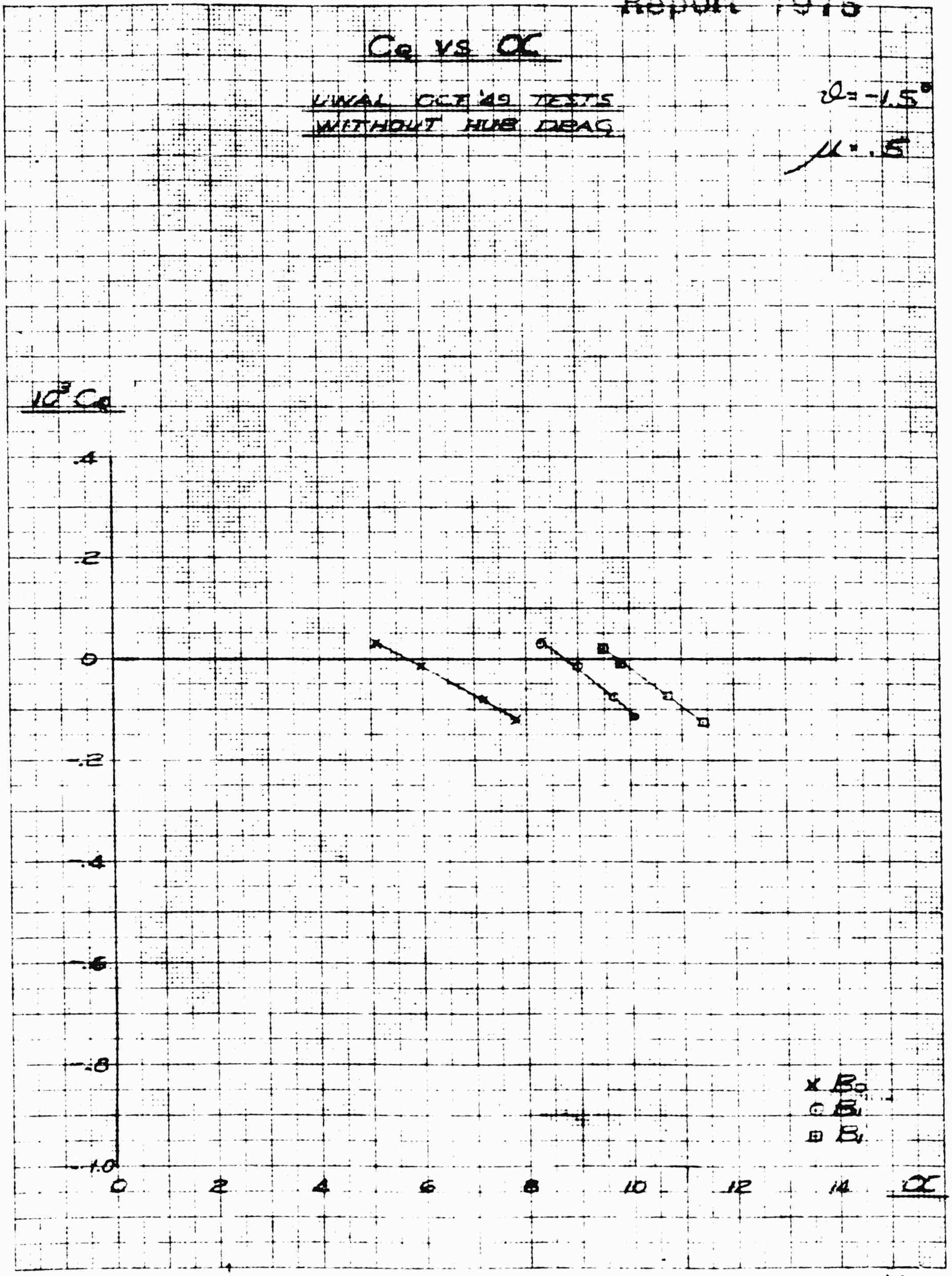
KEUFFEL & ESSER CO.
No 359-14 Millimeters, 5 mm lines accented, ... heavy

CONFIDENTIAL

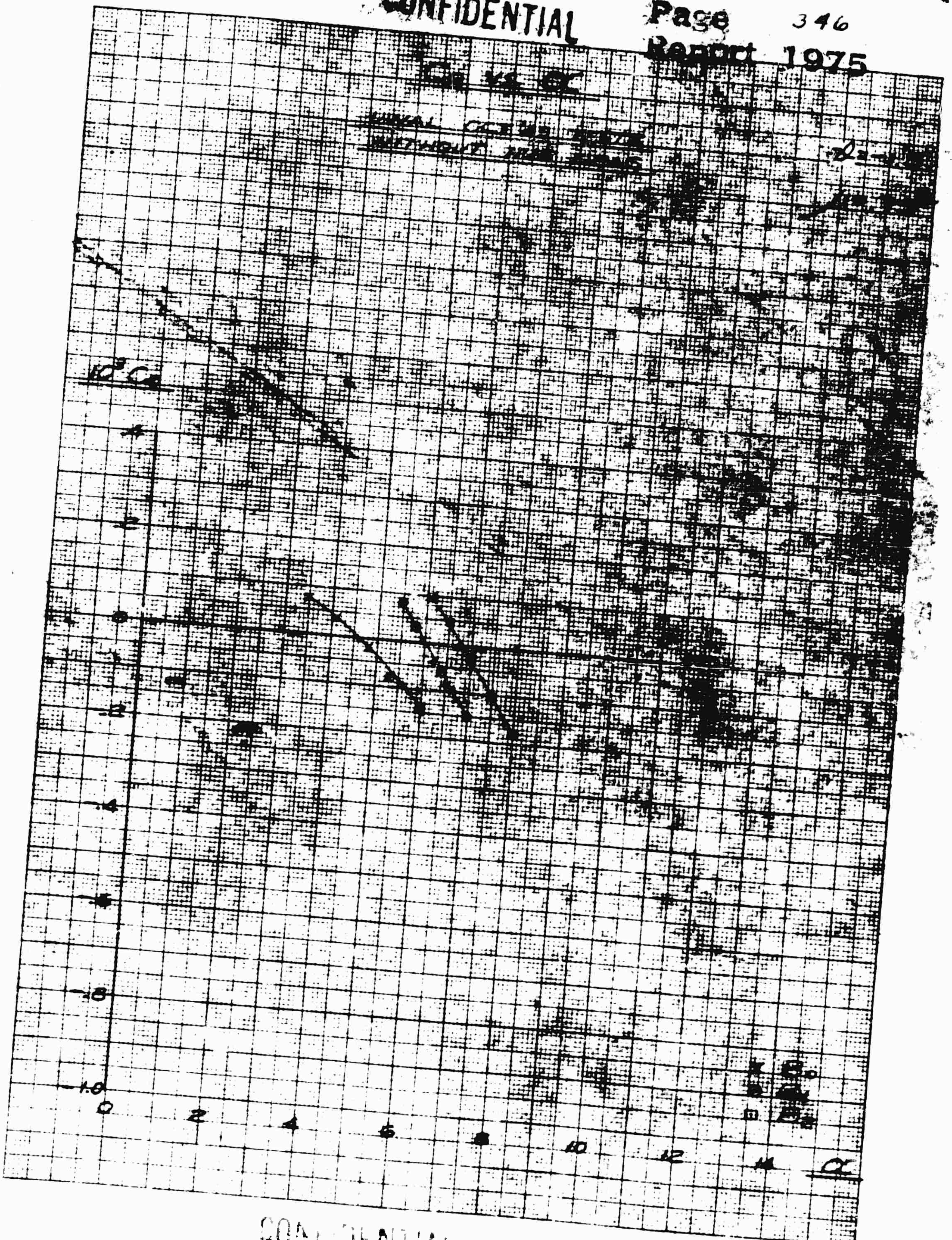
Page 344
Report 1975



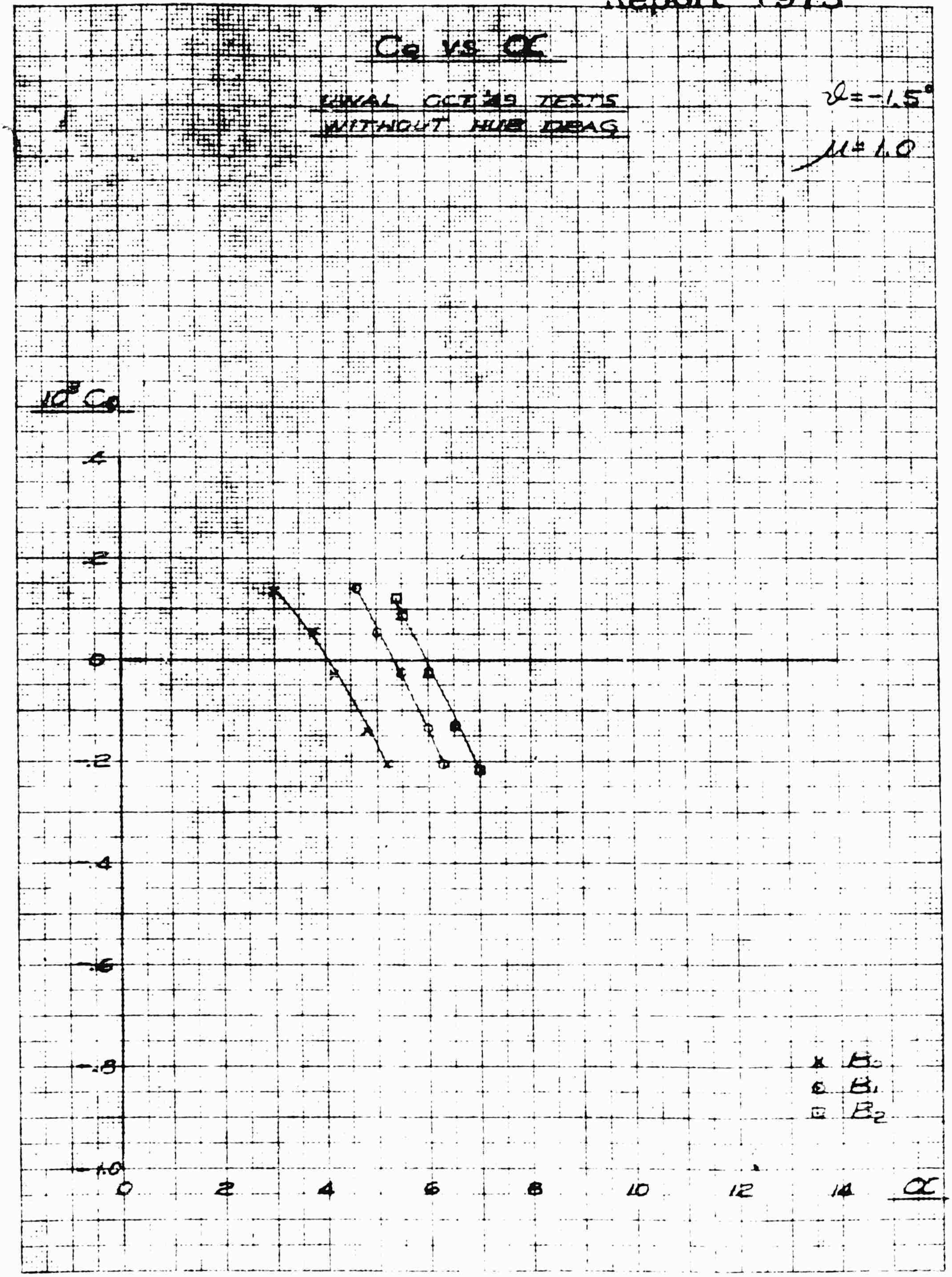
KEUFFEL & ESSER CO.



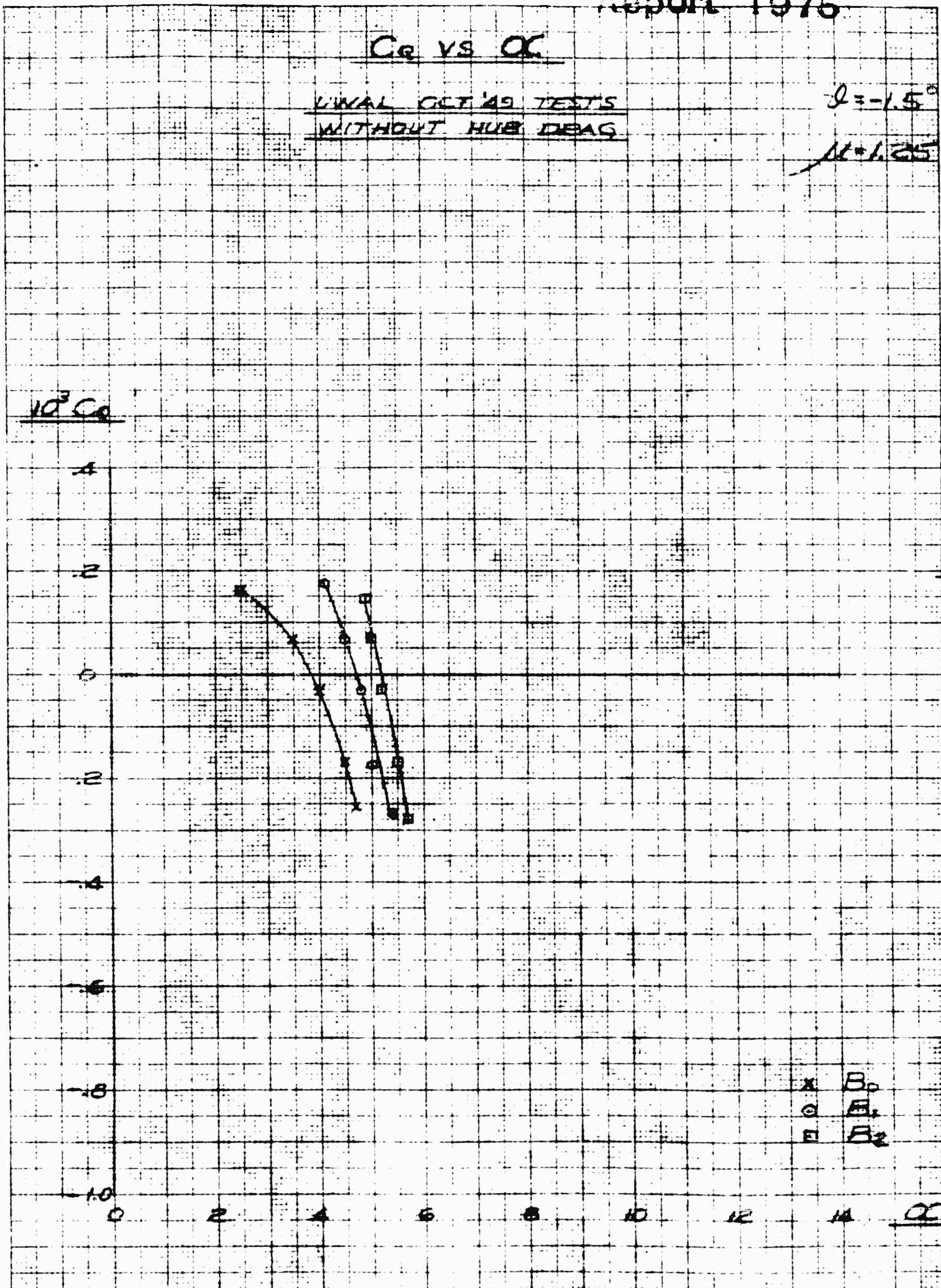
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm. lines accented, cm. lines heavy



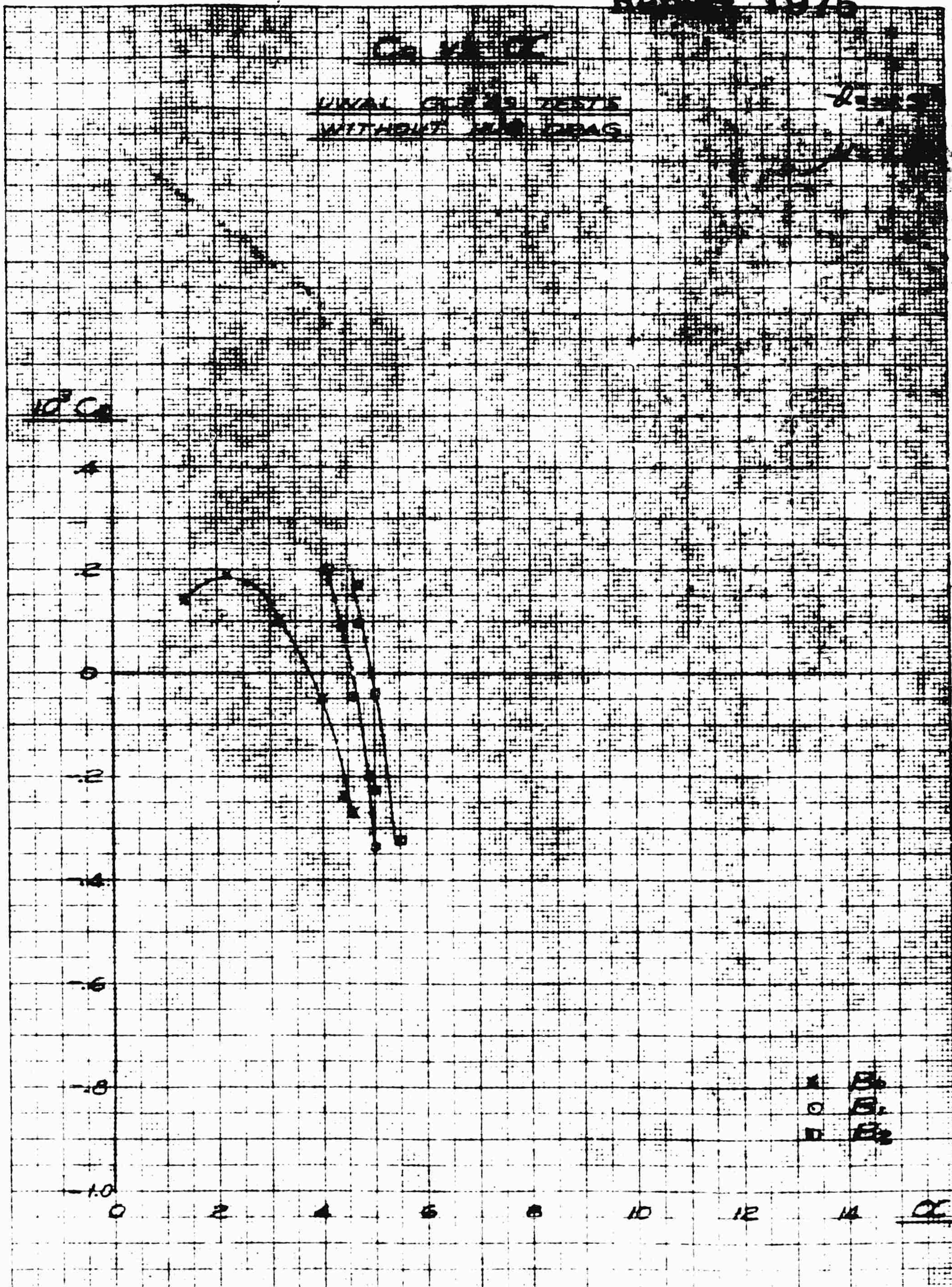
KEUFFEL & ESSER CO.
No 359 14. Millimeters, 5 mm lines accented, cm lines heavy.



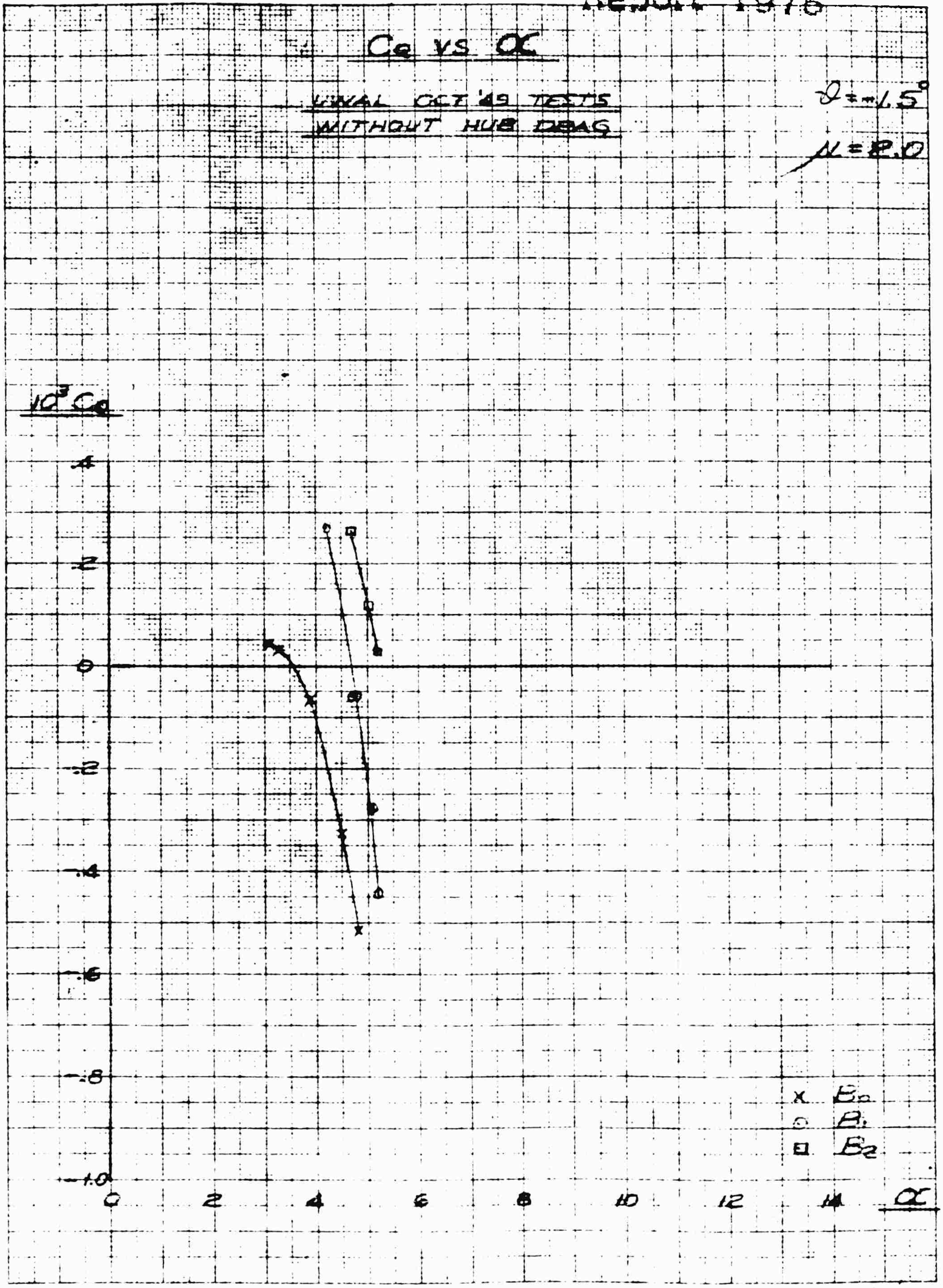
KEUFFEL & ESSER CO.
No. 359-14 Millimeters, 5 mm lines accented, cm lines heavy



KEUFFEL & ESSER CO.
No. 359 14 millimeters, 5 mm lines accented cm lines heavy

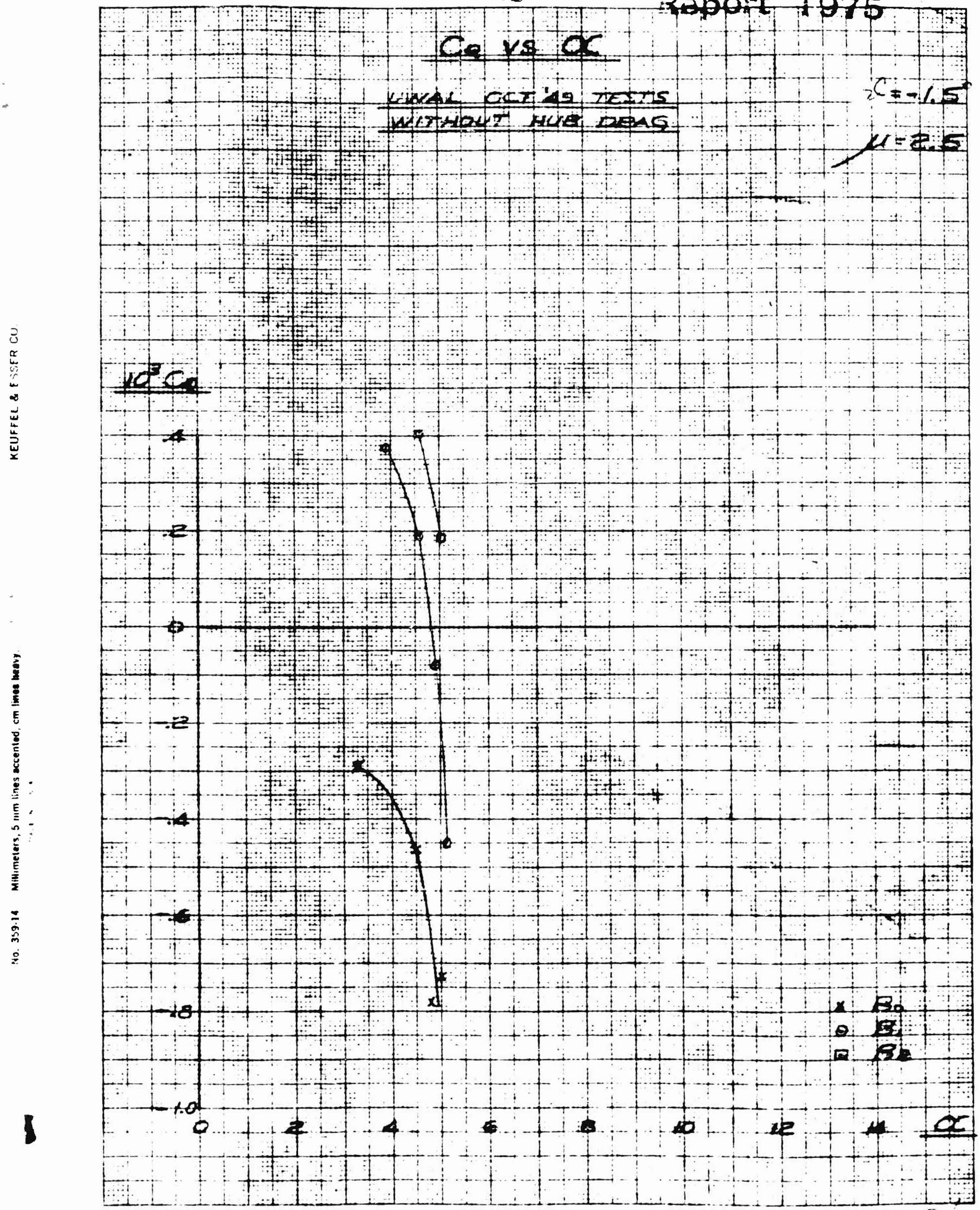


KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented cm lines heavy.



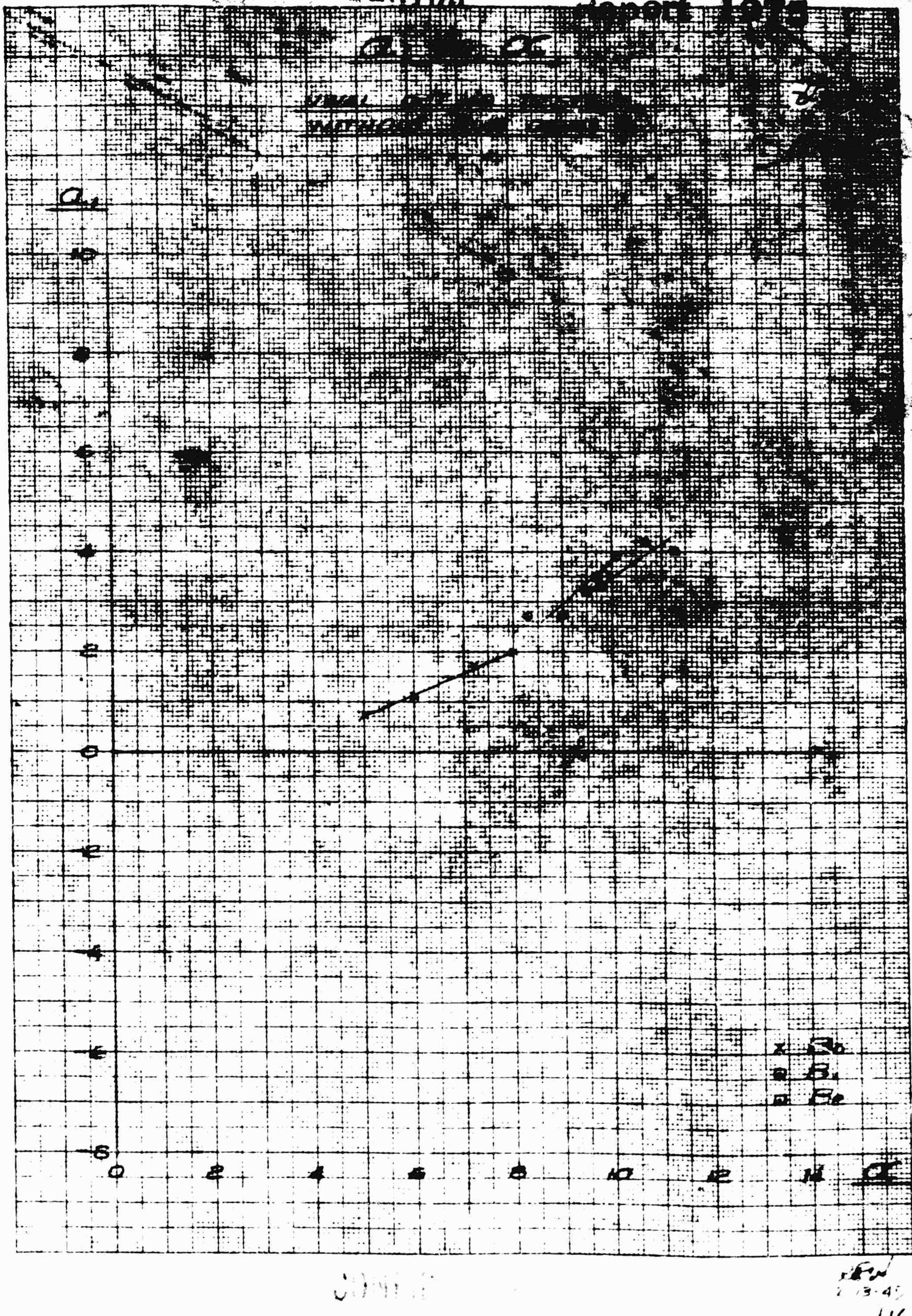
KEUFFEL & ESSER CO.
No 359 14 Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



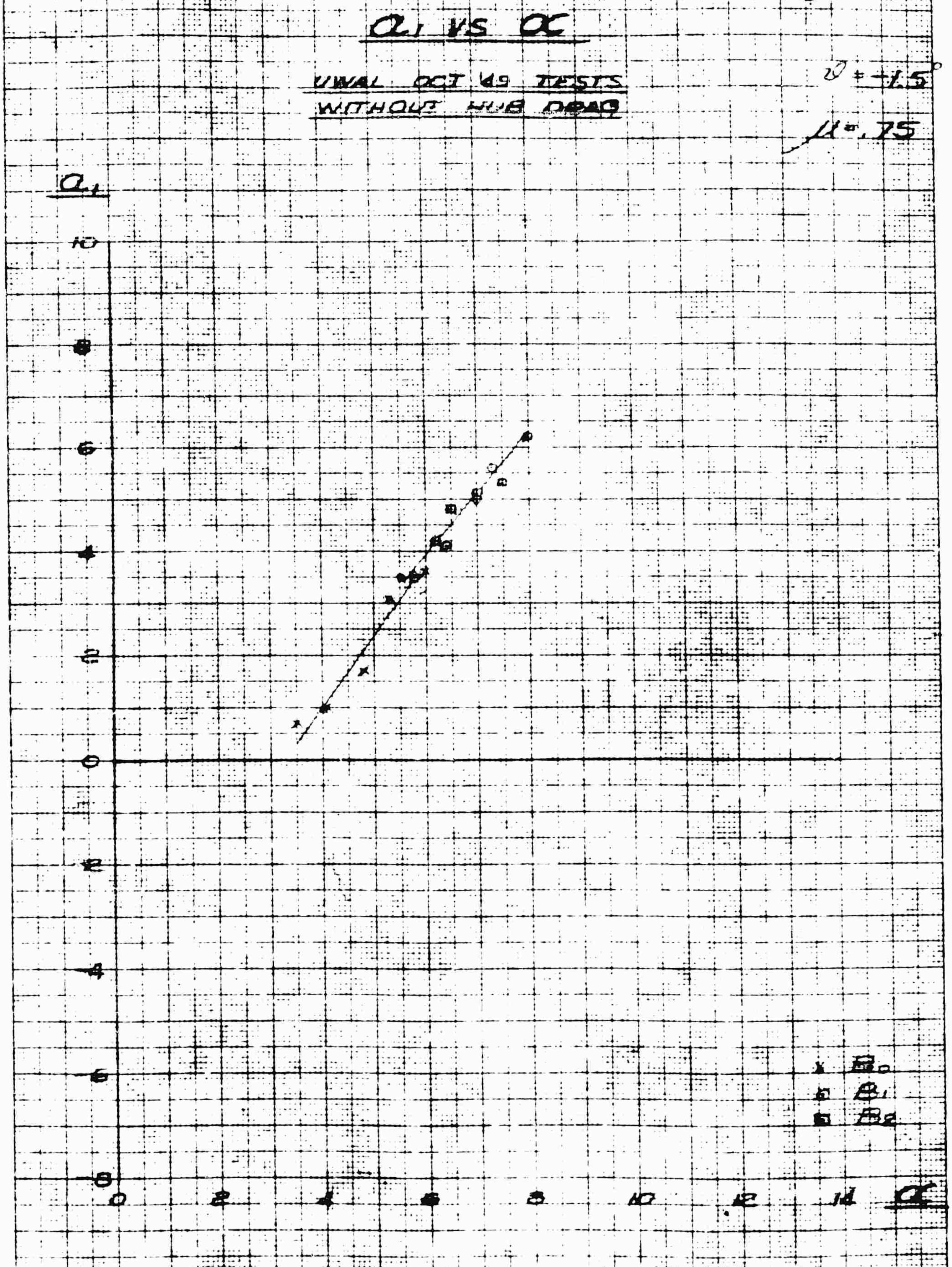
CONFIDENTIAL

115

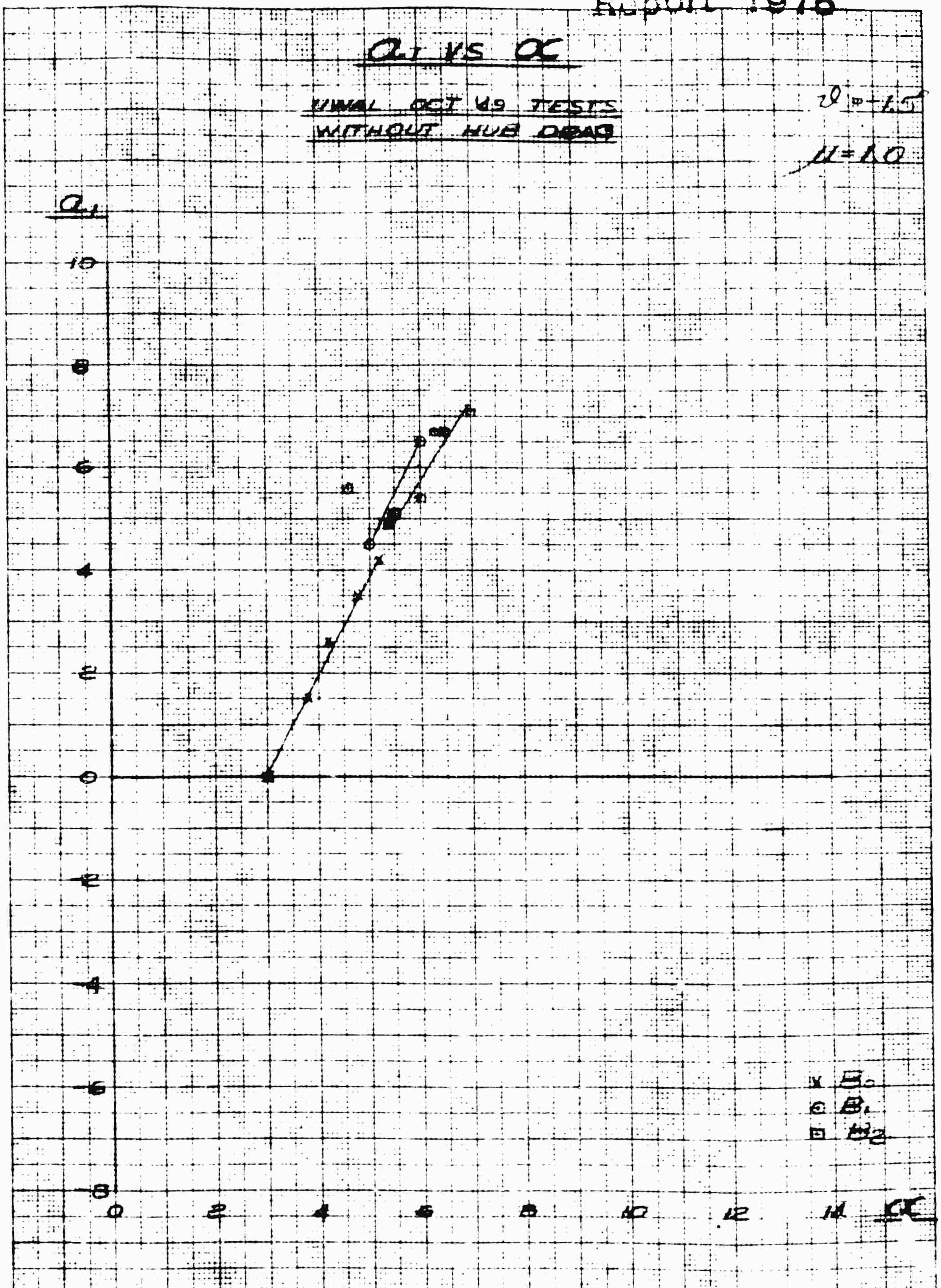


KEUFFEL & ESSER CO.

No 359-14 Millimeters, 5 mm lines accented, cm lines heavy.



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

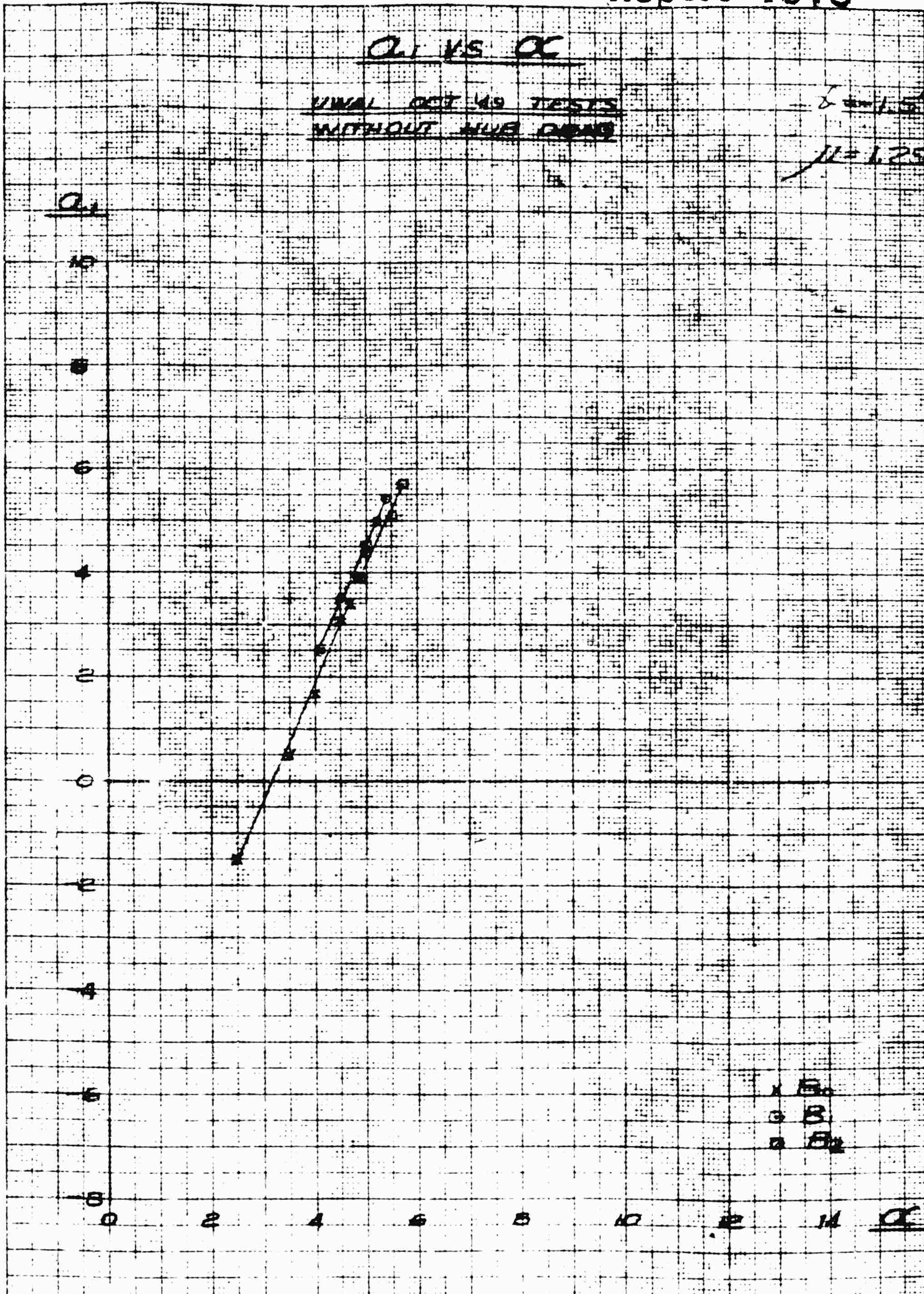


KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

Page 355

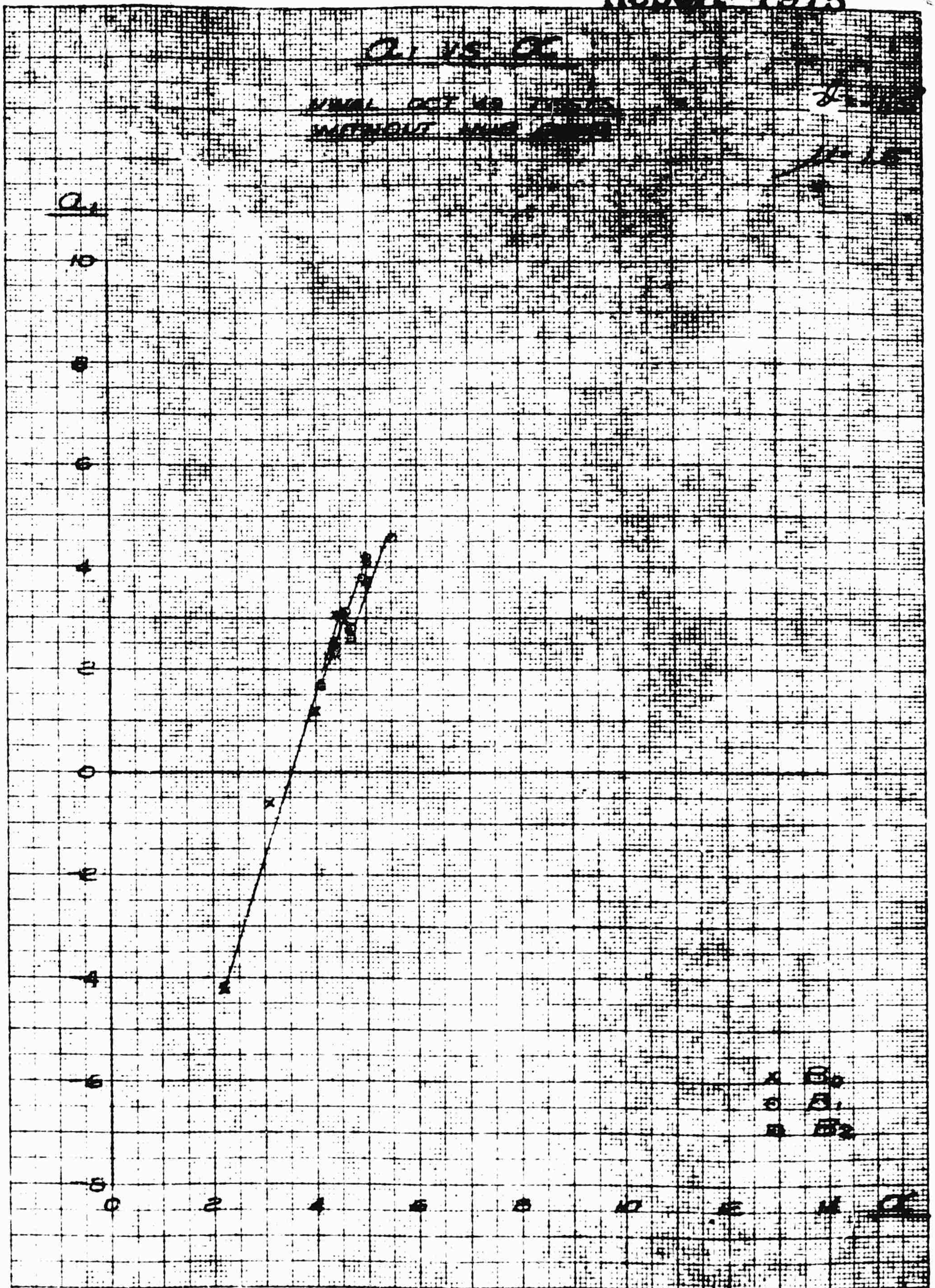
Report 1975



KEUFFEL & ESSER CO.

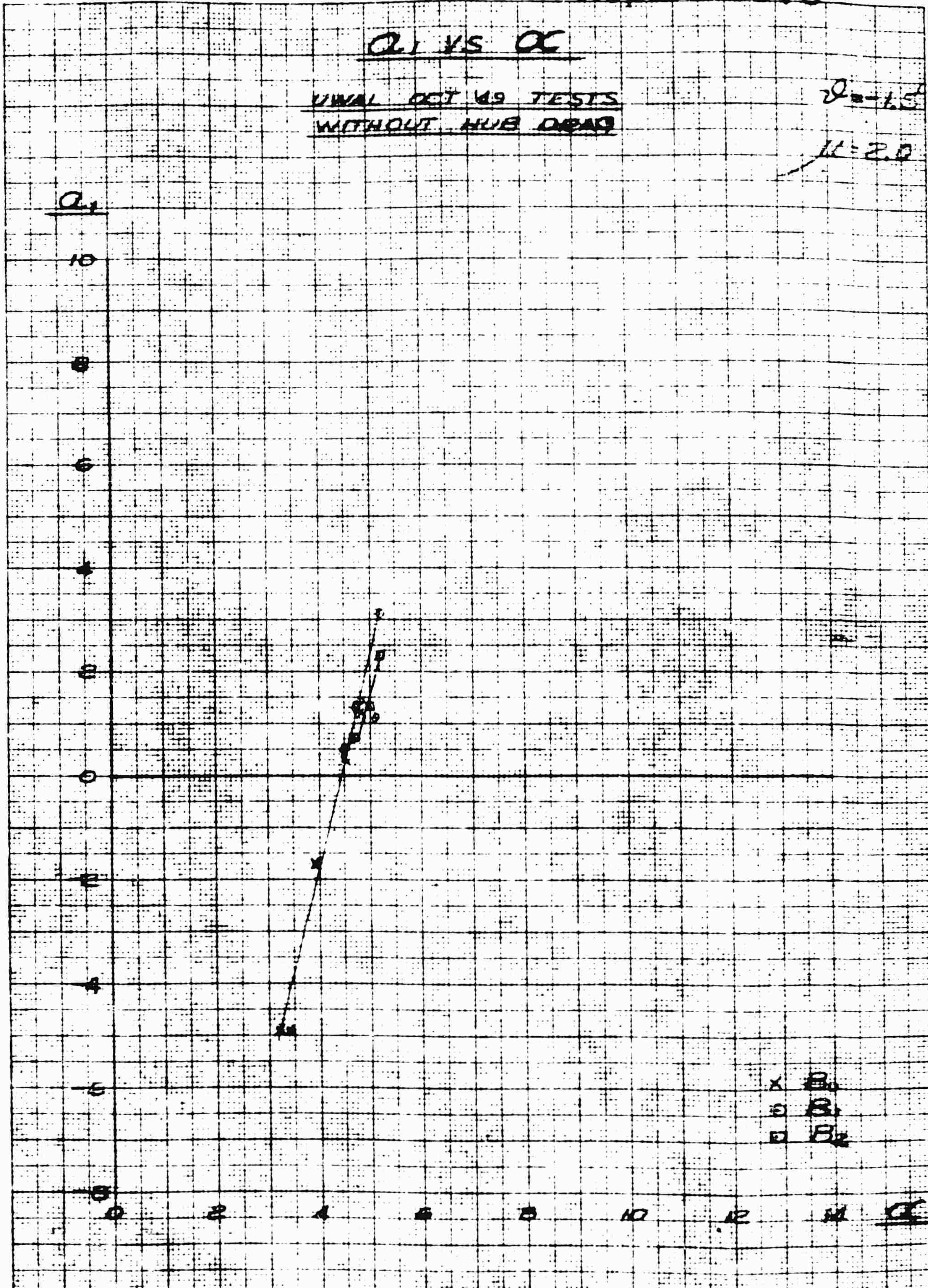
No. 359 14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL



KEUFFEL & ESSER CO.
No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.

12-13-49

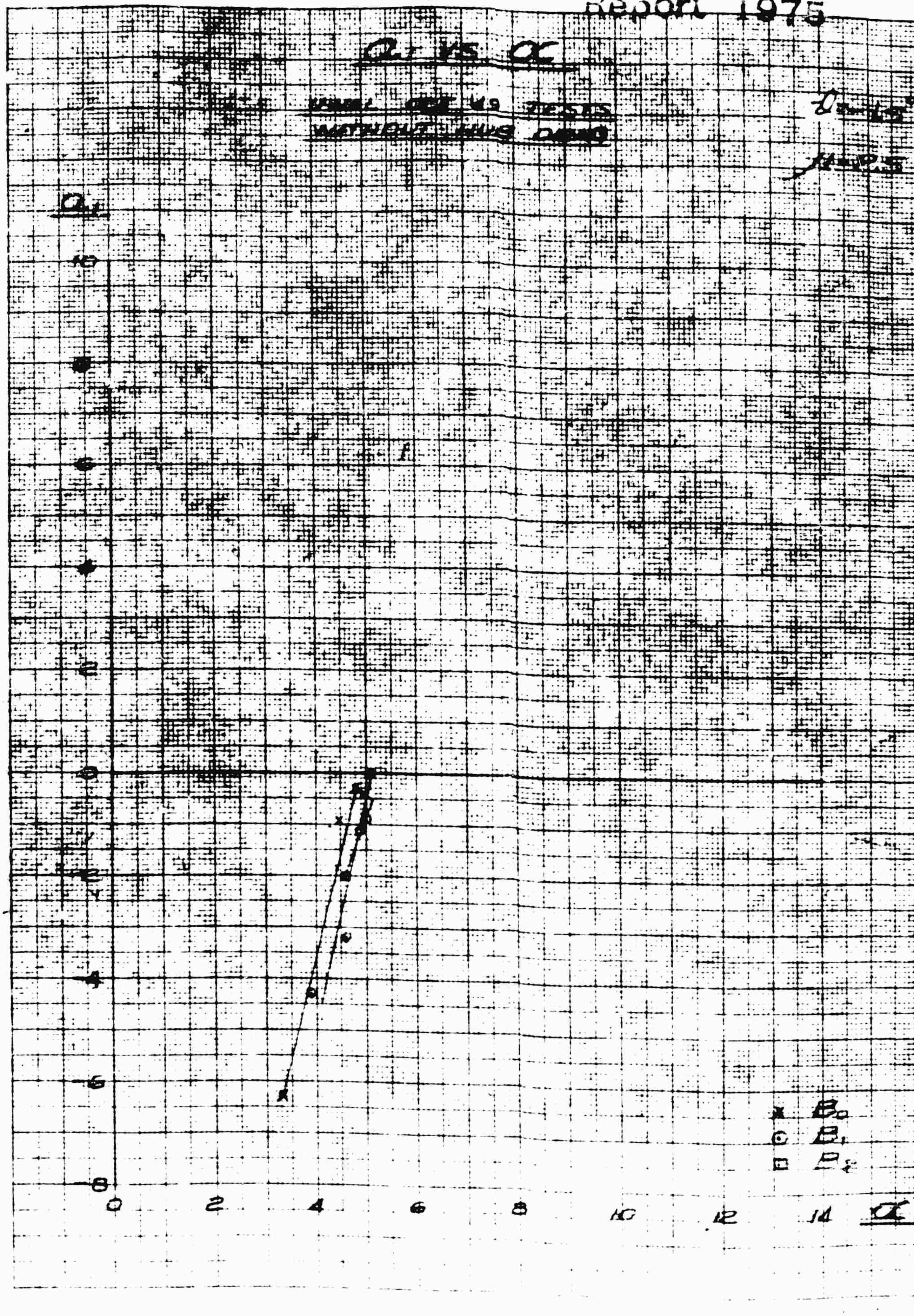


KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy

CONFIDENTIAL

Page 358
Report 1975



KEUFFEL & ESSER CO.

No. 359-14. Millimeters, 5 mm lines accented, cm lines heavy.